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AERODYNAMIC CHARACTERISTICS FROM MACH 1.50 TO 2.86 OF A LIFTING ENTRY VEHICLE ALONE, WITH ADAPTER SECTIONS, AND WITH A SATURN LAUNCH VEHICLE

by John T. McShera, Jr., and James F. Campbell

Langley Research Center

Langley Station, Hampton, Va.

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AERODYNAMIC CHARACTERISTICS FROM MACH 1.50 TO 2.86 OF A LIFTING ENTRY VEHICLE ALONE, WITH ADAPTER SECTIONS, AND WITH A SATURN LAUNCH VEHICLE*

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SUMMARY

An investigation was conducted in the Langley Unitary Plan wind tunnel to determine the aerodynamic characteristics of an HL-10 (horizontal lander 10) entry vehicle with a canopy and a canopy extension and with several arrangements of vertical stabilizing surfaces, the effect of launch-vehicle adapter sections on the overall loading characteristics of the entry vehicle, and the aerodynamic characteristics of the Saturn launch vehicle attached to the entry vehicle with a 45° conic adapter section.

The results showed that the canopy and canopy extension of the entry vehicle had a slight stabilizing effect on the static stability at trim, little effect on the maximum trimmed lift-drag ratio, and a stabilizing effect on the directional stability. This slight increase in longitudinal stability at trim, however, resulted in noticeable decreases in trim angles of attack. An increase in the area of the center fin increased the low-angle-of-attack directional stability of the tip-fin body, but because of the adverse effect of increase in angle of attack on the directional-stability contribution of the center fin, the entry vehicle was unstable at high angles of attack and low Mach numbers even with the larger center fin.

Use of the launch-vehicle adapter sections attached to the entry vehicle resulted in a forward shift in the entry-vehicle center of load at the lower angles of attack. In comparison with a nonlifting vehicle, the lifting entry vehicle of the present investigation exerted a longitudinal destabilizing influence on the complete Saturn launch system and introduced significant nonlinearities in pitching-moment-coefficient curves.

INTRODUCTION

An investigation has been undertaken at the Langley Research Center to determine the aerodynamic characteristics of a manned lifting entry vehicle having a maximum hypersonic lift-drag ratio of about 1.0. After an extensive

*Title, Unclassified.

review of configuration types and analysis of hypersonic and low-subsonic results on some selected preliminary configurations (for example, refs. 1 to 3), one vehicle shape was selected for further study. The vehicle has been designated HL-10 (horizontal lander 10). The results reported in references 4 and 5 indicate that for the HL-10 with tip fins D-1 and center fin E, low directional stability is a problem area at low supersonic speeds.

As part of the general investigation of this vehicle, the present program was aimed at providing information on the effect of a canopy and a canopy extension on the stability of the vehicle alone and on the effect of changes in the center vertical fin on the directional-stability characteristics. In addition, the effect of launch-vehicle adapter sections on the overall loading characteristics of the vehicle alone was determined. Included in this paper are results for the HL-10 entry vehicle attached to the Saturn launch vehicle with the 45° conic adapter section.

The results were obtained in the Langley Unitary Plan wind tunnel for the entry vehicle over an angle-of-attack range from about -7° to about 36° and for the entry vehicle attached to the Saturn launch vehicle from about -6° to about 20°.

SYMBOLS

The results are presented as force and moment coefficients with lift, drag, and pitching moment referred to the stability-axis system and rolling moment, yawing moment, and side force referred to the body-axis system.

The reference center of moments for the entry configuration alone and with adapter sections was located at 53 percent of the body length behind the nose, and at 1.25 percent of the body length below the body reference line. For the Saturn launch vehicle attached to the entry vehicle (launch configuration), the reference center was on the launch-vehicle center line and 68.5 percent of the total length behind the nose of the entry vehicle. Zero angle on all control surfaces is defined as that condition where the surface is in line with the normal contours of elements of the model immediately upstream of the surface.

b — body reference span (for entry configuration, 10.310 in.; for launch system, diameter of circle which would enclose first-stage tanks, 3.392 in.)

C_D — drag coefficient, $\frac{\text{Drag}}{qS}$

C_L — lift coefficient, $\frac{\text{Lift}}{qS}$

C_l — rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$

C_{l_β} effective-dihedral parameter, $\frac{\Delta C_l}{\Delta \beta}$, per deg

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSl}$

$C_{m_{\alpha,trim}}$ longitudinal-stability parameter at trim, $\frac{\Delta C_m}{\Delta \alpha}$, per deg

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$

C_{n_β} directional-stability parameter, $\frac{\Delta C_n}{\Delta \beta}$, per deg

C_Y side-force coefficient, $\frac{\text{Side force}}{qS}$

C_{Y_β} lateral-force parameter, $\frac{\Delta C_Y}{\Delta \beta}$, per deg

l body reference length (for entry configuration, 16.00 in.; for launch system, diameter of circle which would enclose first-stage tanks, 3.392 in.)

L/D lift-drag ratio, C_L/C_D

$(L/D)_{max,trim}$ maximum trimmed lift-drag ratio

M Mach number

q free-stream dynamic pressure, lb/sq ft

r radius

S reference area (for entry configuration, planform area, 0.634 sq ft; for launch system, cross-sectional area of circle which would enclose first-stage tanks, 0.06275 sq ft)

X,Y,Z longitudinal, lateral, and vertical body axes, respectively

x,y,z ordinates along X, Y, and Z body axes, respectively, in.

α angle of attack referred to body reference line, deg

α_{nom} nominal angle of attack (to nearest degree)

α_{trim} angle of attack for trim, deg

β angle of sideslip referred to plane of symmetry, deg

δ_a resultant angle of roll-control flap (positive deflection generates negative rolling moment), $\delta_{e,right} - \delta_{e,left}$, deg

δ_e resultant angle of pitch-control flaps (positive when trailing edge is down), $\frac{\delta_{e,right} + \delta_{e,left}}{2}$, deg

APPARATUS AND PROCEDURE

Wind Tunnel

The tests were conducted in the low Mach number test section of the Langley Unitary Plan wind tunnel. The tunnel is a variable-pressure continuous-flow type. The test section is 4 feet square and approximately 7 feet in length. The nozzle leading to the test section is of the asymmetric sliding-block type, and the Mach number may be varied continuously through a range from 1.50 to 2.86. Further details of the wind tunnel may be found in reference 6.

Models

Details of the 16-inch entry model are presented in figure 1 and ordinates defining the cross-sectional shape of the model without the tip fins, center fin, canopy, and canopy extension are presented in table I. The entry model has a leading-edge sweep angle of 74°. The body cross section has a rounded top with a flat bottom and blunted leading edges. Directional stability is provided by two tip fins rolled out approximately 25° from the vertical and toed in parallel to the wing leading edges. These tip fins are designated D-1, which is the same designation used in reference 4. The two center-fin arrangements are illustrated in figure 2. The center fin is located in the plane of symmetry and has a blunted 6° wedge airfoil section. The larger center fin, designated E, has previously been investigated and some of the results are presented in references 4 and 5. The smaller center fin, designated O, was obtained by reducing the span of fin E.

The entry vehicle of the present investigation differs from the vehicle of references 4 and 5 in that a canopy and a canopy extension have been added.

A drawing of the 16-inch entry model and three truncated-cone—cylinder adapter sections is presented in figure 3. The adapter sections represent the section of the launch system that attaches the entry vehicle to the Saturn second stage. By considering these adapter sections as a reference size, the 16-inch entry-vehicle model would have an equivalent full-scale length of 31.5 feet. Three adapter sections (designated A, B, and C) were used in this investigation. These adapter sections had a constant length of 12.22 inches; adapters A, B, and C had a 45°, 35°, and 25° half-cone angle, respectively. During this phase of the investigation a windshield cover was provided for the surface of the canopy windshield, and abort rockets were added.

The model of the launch system (Saturn launch vehicle, 45° adapter section, and entry vehicle) is shown in figure 4. The entry model of this configuration has abort rockets and the windshield cover for the canopy. Existing models were used when an entry model was attached to a launch-vehicle model having a scale of 0.0132. The entry model had an equivalent full-scale length of 28.4 feet.

Photographs of models of the entry vehicle alone and with launch-vehicle adapter B are shown in figure 5.

Test Conditions

The test conditions are summarized in the following table:

Mach number	Stagnation temperature, °F	Stagnation pressure, lb/sq ft abs	Reynolds number per foot
Entry vehicle alone and with adapter sections			
1.50	125	885	1.59×10^6
1.80	125	969	1.59
2.16	125	1133	1.59
2.86	125	1624	1.59
Launch system			
1.57	125	1442	2.7×10^6
2.16	125	1882	2.8
2.86	125	2613	2.9

The tests on the entry vehicle alone and with the launch-vehicle adapter sections were made over an angle-of-attack range from -7° to 36° and at angles of sideslip of about 0° and 5°. Six-component force and moment measurements were made on the entry vehicle alone and with the adapter sections. The moment center of both configurations was the same. When the entry vehicle was attached to the adapter sections, a small but finite separation existed between the model and the adapter to prevent nonaerodynamic interference between parts.

The investigation of the launch configuration was made over an angle-of-attack range from -6° to 20° and at an angle of sideslip of 0°. The dewpoint temperature for all tests was maintained below -30° F to eliminate any significant condensation effects. Data at angles of attack above 32° at $M = 1.50$ are possibly affected by reflected shock waves. This problem is not evident at the higher test Mach numbers.

Accuracies

The data have been corrected for flow angularity, and the balance-sting deflection due to load has been accounted for in the computation of the angles of attack and sideslip. The data have not been corrected to free-stream conditions at the model base.

The accuracy of the individually measured quantities and coefficients based on calibrations of the balance and repeatability of the data is estimated to be within the following limits:

C_L	± 0.01
C_m	± 0.01
C_D	± 0.001
C_l	± 0.002
C_Y	± 0.002
C_n	± 0.003
β, deg	± 0.1
α, deg	± 0.1
M	± 0.015

PRESENTATION OF RESULTS

The results of this investigation are presented in the following figures:

Figure

RESULTS AND DISCUSSION

Entry Vehicle Alone

Longitudinal characteristics.- The results in figure 7 show that addition of the tip fins increased the longitudinal stability and the lift-curve slope of the entry configuration because of the rolled-out orientation of the fins. The tip fins also decreased the lift-drag ratio. Both the stability and performance effects of the tip fins decrease with increase in Mach number.

The longitudinal characteristics of the entry configuration shown in figure 8 are summarized in figure 9 at trim angles of attack. Presented also, in order to show the effect of canopy and canopy extension, are the longitudinal characteristics reported in reference 4 of the HL-10 without canopy and canopy extension. The results show that the canopy and canopy extension had a slight stabilizing effect on the longitudinal-stability parameter at trim and little effect on the maximum trimmed lift-drag ratio within the Mach number range.

It is also shown that for a given elevator deflection lower trim angles of attack are obtained for the model with the canopy and extension than for the model without the canopy and extension. The decreased trim capability is due to the aforementioned increase in stability at high angles of attack for the model with the canopy and extension over that for the model without the canopy and extension. The canopy and the canopy extension, although having some effect on the control effectiveness when the elevator is deflected upward, do not appear to have a significant influence on the static controllability of the configuration.

Lateral characteristics.- The lateral-stability parameters (fig. 10) for the vehicle alone show that the side area provided by the tip fins increases the directional stability of the body at all angles of attack and Mach numbers. Both sizes of center fins provide additional directional stability, but the center-fin contribution diminishes as angle of attack and Mach number increase. The large center fin E, of course, provides a greater stabilizing influence than does the small center fin O under most test conditions. The entry vehicle is not, however, directionally stable at the higher angles of attack and lower Mach numbers ($M = 1.50$ and 1.80), even with the larger center fin combined with the tip fins, because of the reduction in the center-fin contribution to stability with increase in angle of attack.

A comparison of the results presented in this paper and the results from reference 4 for the configuration with center fin E and tip fin D-1 is presented in figure 11 for an angle of attack of 22.5° and shows the effect of the canopy and canopy extension on the directional-stability parameter. These results indicate that the canopy and canopy extension are directionally stabilizing throughout the Mach number range. This stabilizing effect may be expected because the distance between the center-fin centroid and the model reference axis was increased when the fin was mounted on top of the canopy extension. Also the distribution of canopy-extension side area about the center of moments is such that the area behind the center of moments is greater than the area forward of the center of moments.

The lateral-stability results (fig. 12) also show that deflection of the longitudinal controls had no significant effect on the characteristics of the entry configuration.

Entry Vehicle With Adapter Sections

An indication of the effect of adapter sections on the overall loading characteristics of the entry vehicle is shown by the longitudinal characteristics of figure 13. These results indicate that the adapters, in general, decrease configuration lift and increase positively the pitching moment. The lift decrease and pitch increase are not proportional to adapter conic angle, angle of attack, or Mach number.

The loss in lift and the increase in pitching moment occurring in the lower angle-of-attack range indicate a forward movement in the entry-vehicle center of load. At the higher angles of attack, where for adapter A some increase in configuration lift and negative change in pitching moment occurs, a rearward change in the vehicle center of load is indicated.

An indication of the effect of the adapter sections on the airflow characteristics about the entry vehicle is seen in the schlieren photographs, figures 6(b) and 6(c). Note varying amounts of separation on the lower surface of the entry vehicle when adapter sections and angles of attack are changed.

Launch System

The longitudinal characteristics of the lifting entry vehicle combined with a Saturn launch vehicle are presented in figure 14. In comparison with a nonlifting vehicle (see ref. 7), the lifting entry vehicle of the present investigation, as expected, destabilizes the complete launch system. It should be noted in making this comparison that allowances must be made for existing differences in launch-vehicle geometry, such as fins, protuberances, and nose shapes. The results of the present investigation also show considerable change in pitching moment at any small angle of attack with change in Mach number. This change in pitching-moment levels, as well as the nonlinearity of the pitching-moment-coefficient curves at relatively low angles of attack (fig. 14) indicates that first-stage control programming would be more complicated with the lifting entry vehicle of the present investigation than with the nonlifting vehicle.

CONCLUSIONS

An investigation was conducted to determine the aerodynamic characteristics of an HL-10 entry vehicle with a canopy and a canopy extension and with several arrangements of vertical stabilizing surfaces, to establish the overall loading changes resulting from several types of launch-vehicle adapter sections, and to determine the aerodynamic characteristics of a Saturn launch vehicle attached to an HL-10 entry vehicle with a 45° conic adapter section. The results indicated the following conclusions:

1. The canopy and canopy extension of the entry vehicle had a slight stabilizing effect on the static stability at trim and little effect on the maximum trimmed lift-drag ratio within the Mach number range. This slight increase in longitudinal stability at trim, however, resulted in noticeable decreases in trim angles of attack.

2. An increase in the area of the center fin increased the low-angle-of-attack directional stability of the tip-fin body, but because of the adverse effect of increase in angle of attack on the directional-stability contribution of the center fin, the entry vehicle was unstable at high angles of attack and low Mach numbers ($M = 1.50$ and 1.80) even with the larger center fin.

3. The canopy and canopy extension slightly increased the level of directional stability at high angles of attack within the Mach number range.

4. Use of the adapter sections with the entry vehicle resulted in a forward change in the entry-vehicle center of load at the lower angles of attack and all test Mach numbers.

5. In comparison with a nonlifting vehicle, the lifting entry vehicle of the present investigation exerted a longitudinal destabilizing influence on the complete launch system and introduced significant changes in the levels of pitching moment as well as appreciable nonlinearities of the pitching-moment-coefficient curves.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 12, 1965.

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[redacted]

TABLE I.- ORDINATES DEFINING CROSS-SECTIONAL SHAPE OF HL-10 WITHOUT TIP FINS, CENTER FIN, CANOPY, AND CANOPY EXTENSION

z/l	y/l
x/l = 0.042	
0.0541	0
.0532	.0083
.0503	.0167
.0441	.0250
.0375	.0306
.0333	.0338
.0250	.0390
.0167	.0431
.0083	.0459
0	.0476
-.0536	0
x/l = 0.083	
0.0681	0
.0668	.0083
.0637	.0167
.0579	.0250
.0502	.0333
.0417	.0392
.0330	.0444
.0250	.0487
.0167	.0521
.0083	.0547
0	.0568
-.0083	.0585
-.0167	.0596
-.0752	0
x/l = 0.125	
0.0737	0
.0729	.0083
.0702	.0167
.0660	.0250
.0594	.0330
.0505	.0417
.0417	.0477
.0333	.0528
.0250	.0571
.0167	.0604
.0083	.0632
0	.0656
-.0083	.0675
-.0167	.0691
-.0250	.0704
-.0333	.0714
-.0904	0
x/l = 0.167	
0.0771	0
.0763	.0083
.0744	.0167
.0712	.0250
.0664	.0333
.0597	.0417
.0512	.0500
.0417	.0565
.0333	.0618
.0250	.0664
.0167	.0701
.0083	.0732
0	.0757
-.0083	.0778
-.0167	.0796
-.0250	.0811
-.0333	.0823
-.0417	.0833
-.0500	.0840
-.1026	0

z/l	y/l
x/l = 0.208	
0.0792	0
.0787	.0083
.0772	.0167
.0747	.0250
.0712	.0333
.0664	.0416
.0592	.0500
.0517	.0583
.0417	.0656
.0333	.0713
.0250	.0760
.0167	.0800
.0083	.0833
0	.0860
-.0083	.0882
-.0167	.0902
-.0250	.0919
-.0333	.0933
-.0417	.0946
-.0500	.0955
-.0583	.0962
-.1126	0
x/l = 0.250	
0.0807	0
.0803	.0083
.0792	.0167
.0773	.0250
.0748	.0333
.0712	.0417
.0666	.0500
.0606	.0583
.0527	.0667
.0458	.0721
.0417	.0754
.0333	.0811
.0250	.0862
.0167	.0902
.0083	.0937
0	.0965
-.0083	.0990
-.0167	.1011
-.0250	.1027
-.0333	.1044
-.0417	.1057
-.0500	.1067
-.0583	.1076
-.0667	.1083
-.1205	0
x/l = 0.292	
0.0817	0
.0814	.0083
.0807	.0167
.0794	.0250
.0774	.0333
.0750	.0417
.0715	.0500
.0672	.0583
.0617	.0667
.0546	.0750
.0500	.0789
.0417	.0858
.0333	.0918
.0250	.0969
.0167	.1010
.0083	.1044
0	.1072
-.0083	.1098

z/l	y/l
x/l = 0.292	
-0.0167	0.1119
-.0250	.1137
-.0333	.1156
-.0417	.1170
-.0500	.1182
-.0583	.1192
-.0667	.1198
-.0750	.1202
-.1268	0
x/l = 0.333	
0.0820	0
.0818	.0083
.0813	.0167
.0803	.0250
.0789	.0333
.0771	.0417
.0747	.0500
.0716	.0583
.0677	.0667
.0627	.0750
.0564	.0833
.0485	.0917
.0417	.0968
.0333	.1027
.0250	.1078
.0167	.1119
.0083	.1152
0	.1179
-.0083	.1204
-.0167	.1227
-.0250	.1250
-.0333	.1267
-.0417	.1282
-.0500	.1296
-.0583	.1306
-.0667	.1317
-.0750	.1321
-.1312	0
x/l = 0.375	
0.0821	0
.0820	.0083
.0816	.0167
.0809	.0250
.0799	.0333
.0783	.0417
.0766	.0500
.0744	.0583
.0714	.0667
.0679	.0750
.0633	.0833
.0576	.0917
.0503	.1000
.0415	.1083
.0333	.1136
.0250	.1187
.0167	.1229
.0083	.1262
0	.1292
-.0083	.1315
-.0167	.1337
-.0250	.1358
-.0333	.1377
-.0417	.1394
-.0500	.1408
-.0583	.1420
-.0667	.1429
-.0750	.1437
-.0833	.1442
-.1334	0

z/l	y/l
x/l = 0.417	
0.0814	0
.0813	.0083
.0811	.0167
.0805	.0250
.0797	.0333
.0786	.0417
.0772	.0500
.0755	.0583
.0733	.0667
.0706	.0750
.0674	.0833
.0633	.0917
.0582	.1000
.0517	.1083
.0437	.1167
.0375	.1211
.0333	.1241
.0250	.1296
.0167	.1339
.0083	.1375
0	.1406
-.0083	.1431
-.0167	.1453
-.0250	.1472
-.0333	.1492
-.0417	.1508
-.0500	.1523
-.0583	.1536
-.0667	.1546
-.0750	.1554
-.0833	.1559
-.1340	0
x/l = 0.458	
0.0800	0
.0799	.0083
.0797	.0167
.0794	.0250
.0788	.0333
.0780	.0417
.0768	.0500
.0755	.0583
.0739	.0667
.0720	.0750
.0694	.0833
.0664	.0917
.0629	.1000
.0581	.1083
.0526	.1167
.0453	.1250
.0363	.1333
.0292	.1379
.0250	.1407
.0167	.1454
.0083	.1491
0	.1521
-.0083	.1549
-.0167	.1571
-.0250	.1592
-.0333	.1611
-.0417	.1627
-.0500	.1642
-.0583	.1654
-.0667	.1664
-.0750	.1672
-.0833	.1677
-.1322	0

z/l	y/l
x/l = 0.500	
0.0782	0
.0782	.0167
.0780	.0250
.0776	.0333
.0770	.0417
.0762	.0500
.0751	.0583
.0738	.0667
.0723	.0750
.0705	.0833
.0682	.0917
.0655	.1000
.0620	.1083
.0579	.1167
.0529	.1250
.0467	.1333
.0390	.1417
.0333	.1458
.0250	.1521
.0167	.1571
.0083	.1612
0	.1643
-.0083	.1672
-.0167	.1694
-.0250	.1715
-.0333	.1733
-.0417	.1750
-.0500	.1763
-.0583	.1775
-.0667	.1785
-.0750	.1792
-.1285	0
x/l = 0.542	
0.0759	0
.0759	.0166
.0758	.0249
.0756	.0332
.0752	.0415
.0747	.0498
.0740	.0581
.0730	.0664
.0718	.0747
.0705	.0830
.0688	.0913
.0666	.0996
.0642	.1079
.0611	.1162
.0575	.1245
.0530	.1328
.0476	.1411
.0410	.1494
.0326	.1577
.0249	.1629
.0166	.1685
.0083	.1729
0	.1764
-.0083	.1790
-.0166	.1815
-.0249	.1834
-.0332	.1853
-.0415	.1869
-.0498	.1882
-.0581	.1893
-.0664	.1902
-.1229	0

z/l	y/l
x/l = 0.583	
0.0741	0
.0741	.0104
.0740	.0271
.0735	.0437
.0726	.0604
.0710	.0771
.0671	.0937
.0668	.1020
.0651	.1104
.0626	.1187
.0596	.1270
.0563	.1354
.0521	.1437
.0471	.1520
.0412	.1604
.0337	.1687
.0250	.1756
.0167	.1813
.0083	.1860
0	.1897
-.0083	.1926
-.0167	.1949
-.0250	.1970
-.0333	.1988
-.0417	.2003
-.0500	.2017
-.0583	.2028
-.1156	0
x/l = 0.625	
0.0716	0
.0716	.0104
.0716	.0271
.0713	.0437
.0707	.0604
.0696	.0771
.0678	.0937
.0655	.1104
.0637	.1187
.0616	.1270
.0591	.1354
.0558	.1437
.0521	.1520
.0478	.1604
.0429	.1687
.0365	.1770
.0292	.1842
.0250	.1878
.0167	.1941
.0083	.1991
0	.2028
-.0083	.2057
-.0167	.2080
-.0250	.2101
-.0333	.2118
-.0417	.2132
-.0500	.2143
-.1073	0
x/l = 0.667	
0.0687	0
.0686	.0208
.0686	.0375
.0684	.0541
.0678	.0708
.0669	.0875
.0655	.1041
.0634	.1208
.0601	.1374
.0580	.1458

z/l	y/l
x/l = 0.667	
0.0553	0.1541
.0522	.1624
.0483	.1708
.0439	.1791
.0385	.1874
.0317	.1958
.0250	.2015
.0167	.2080
.0083	.2128
0	.2167
-.0083	.2197
-.0167	.2218
-.0250	.2237
-.0333	.2254
-.0417	.2264
-.0986	0
x/l = 0.708	
0.0654	0
.0653	.0417
.0651	.0583
.0650	.0750
.0643	.0916
.0634	.1083
.0617	.1250
.0596	.1416
.0582	.1499
.0563	.1583
.0542	.1666
.0517	.1749
.0487	.1833
.0446	.1916
.0398	.1999
.0340	.2083
.0292	.2130
.0250	.2168
.0167	.2235
.0083	.2283
0	.2317
-.0083	.2343
-.0167	.2363
-.0250	.2378
-.0333	.2390
-.0889	0
x/l = 0.750	
0.0617	0
.0616	.0625
.0615	.0791
.0611	.0958
.0606	.1125
.0596	.1291
.0581	.1458
.0561	.1624
.0533	.1791
.0488	.1958
.0458	.2041
.0421	.2124
.0372	.2207
.0333	.2256
.0292	.2307
.0250	.2347
.0167	.2409
.0083	.2447
0	.2470
-.0083	.2491
-.0167	.2504
-.0250	.2511
-.0785	0

z/l	y/l
x/l = 0.792	
0.0578	0
.0577	.0937
.0576	.1104
.0573	.1270
.0569	.1437
.0561	.1604
.0549	.1770
.0532	.1937
.0506	.2103
.0486	.2187
.0460	.2270
.0425	.2353
.0375	.2437
.0333	.2481
.0250	.2551
.0167	.2588
.0083	.2611
0	.2624
-.0083	.2631
-.0167	.2634
-.0673	0
x/l = 0.833	
0.0536	0
.0534	.1666
.0532	.1833
.0528	.1999
.0521	.2166
.0510	.2332
.0482	.2499
.0455	.2582
.0400	.2666
.0333	.2707
.0250	.2736
.0167	.2749
.0083	.2753
0	.2753
-.0563	0
x/l = 0.875	
0.0487	0
-.0452	0
x/l = 0.917	
0.0440	0
-.0341	0
x/l = 0.958	
0.0392	0
-.0227	0
x/l = 1.000	
0.0344	0
-.0125	0

[redacted]

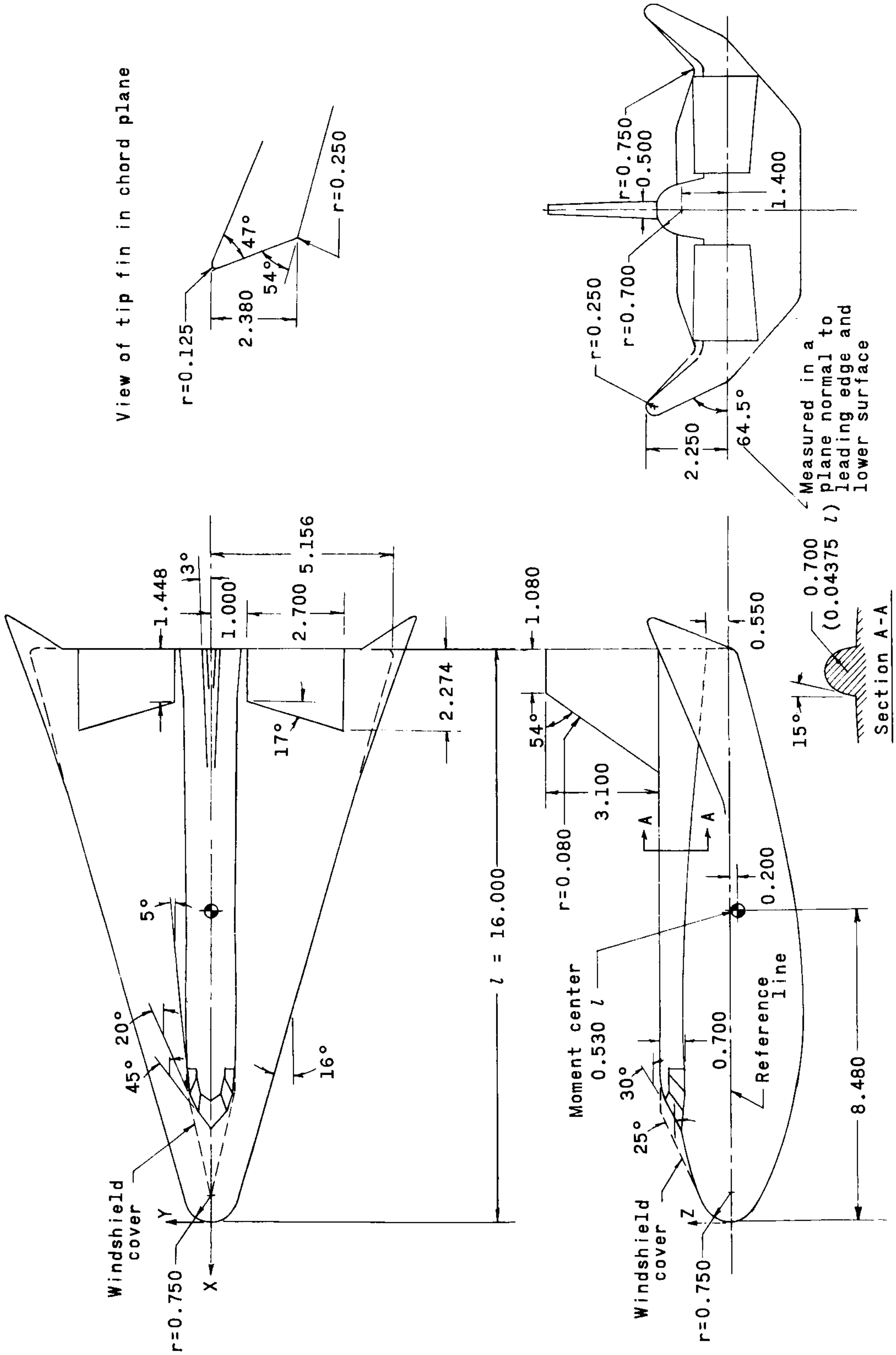

Figure 1.- Model of entry vehicle. (All dimensions in inches unless otherwise specified.)

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[redacted]

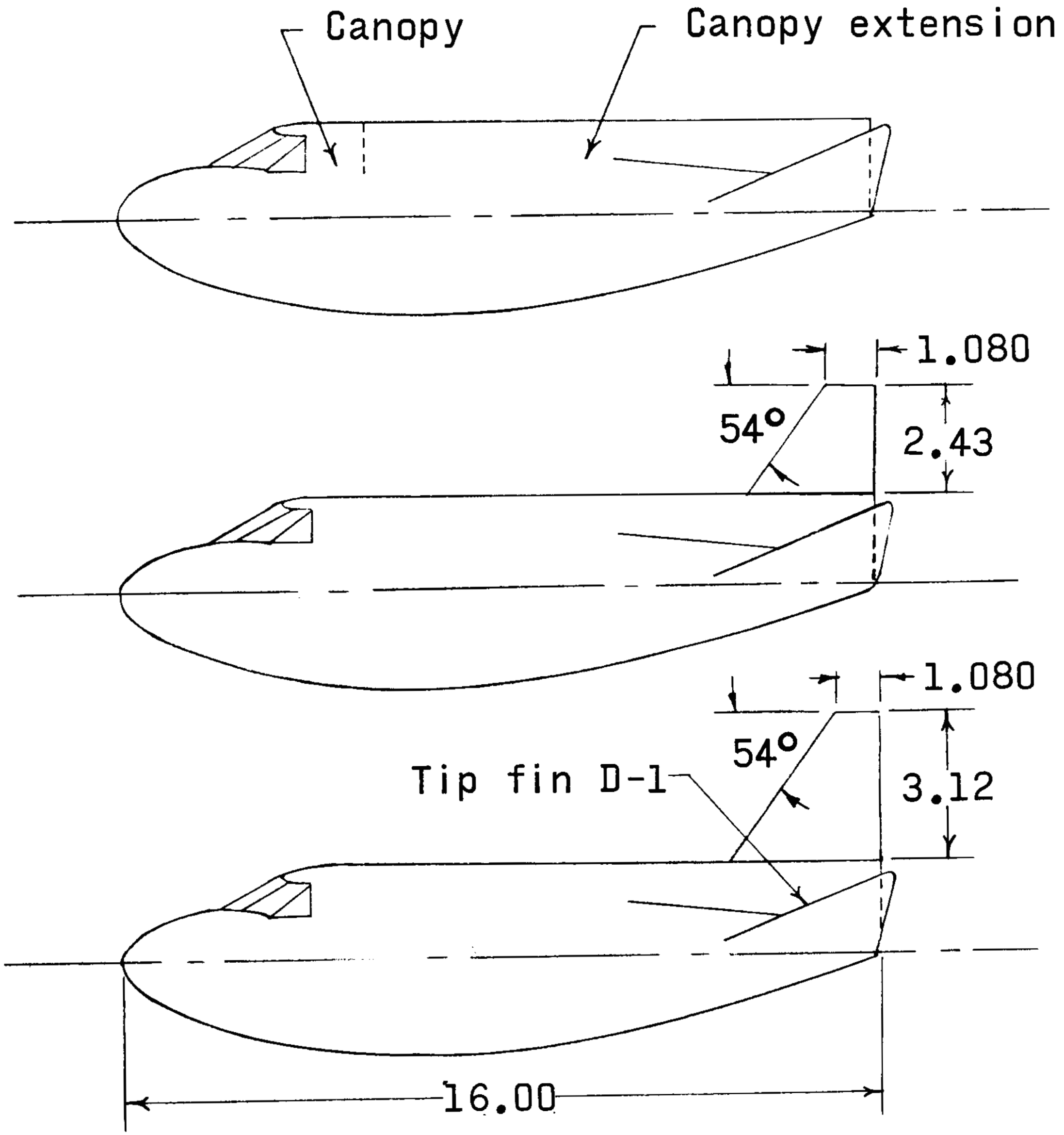

Figure 2.- Entry vehicle with various center-fin arrangements. (All dimensions in inches unless otherwise noted.)

[redacted]

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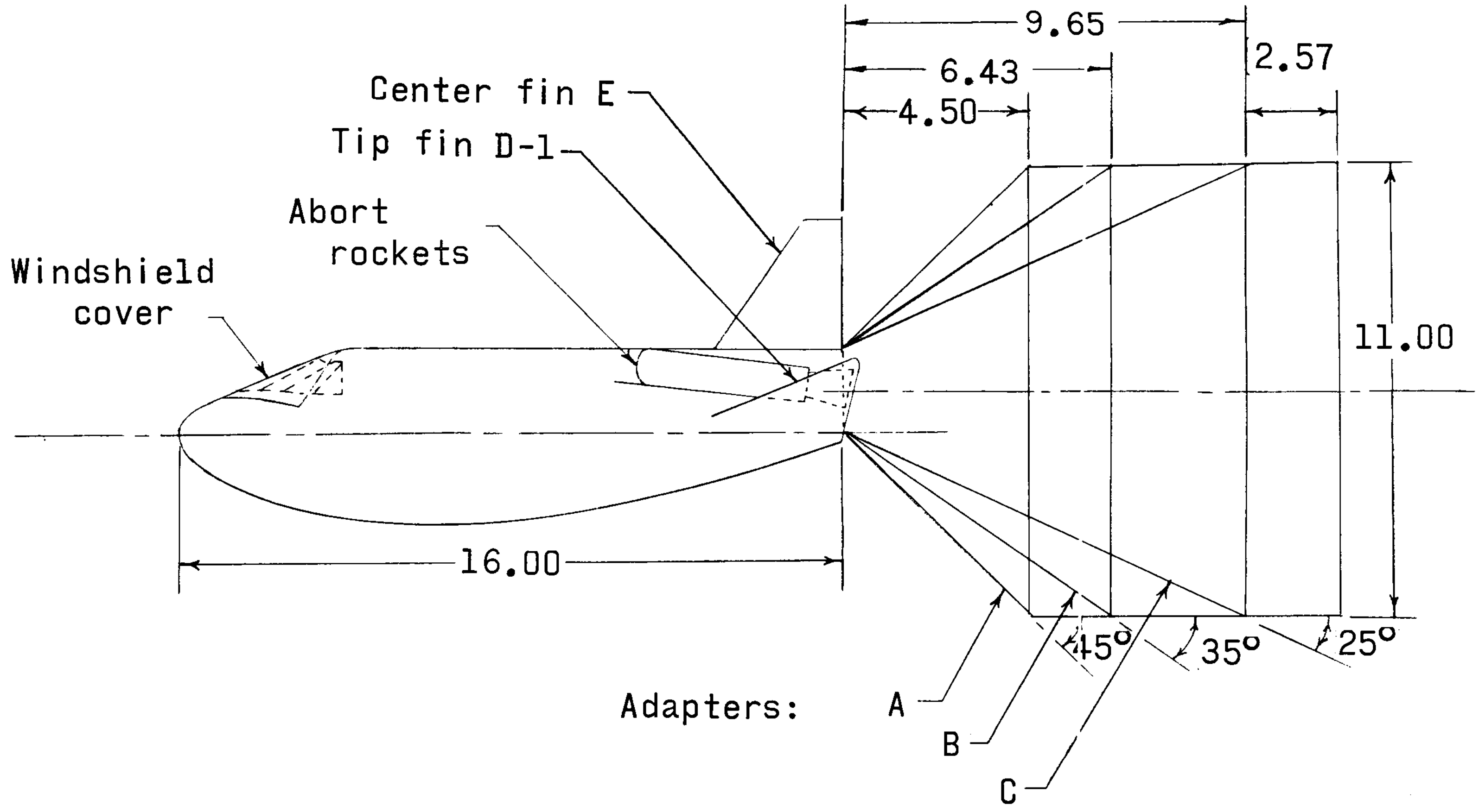


Figure 3.- Model of entry vehicle in presence of launch-vehicle adapter sections. (All dimensions in inches unless otherwise noted.)

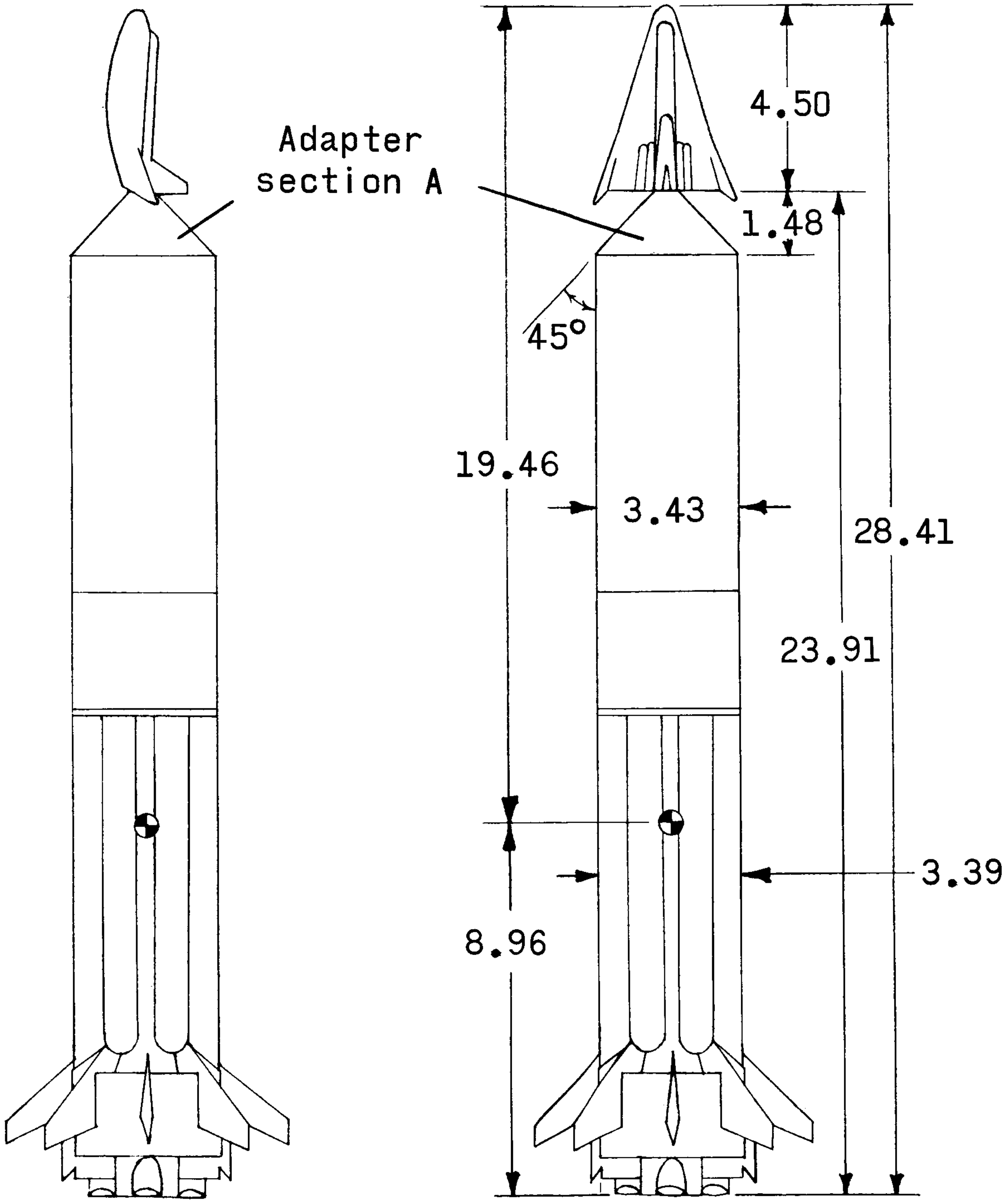
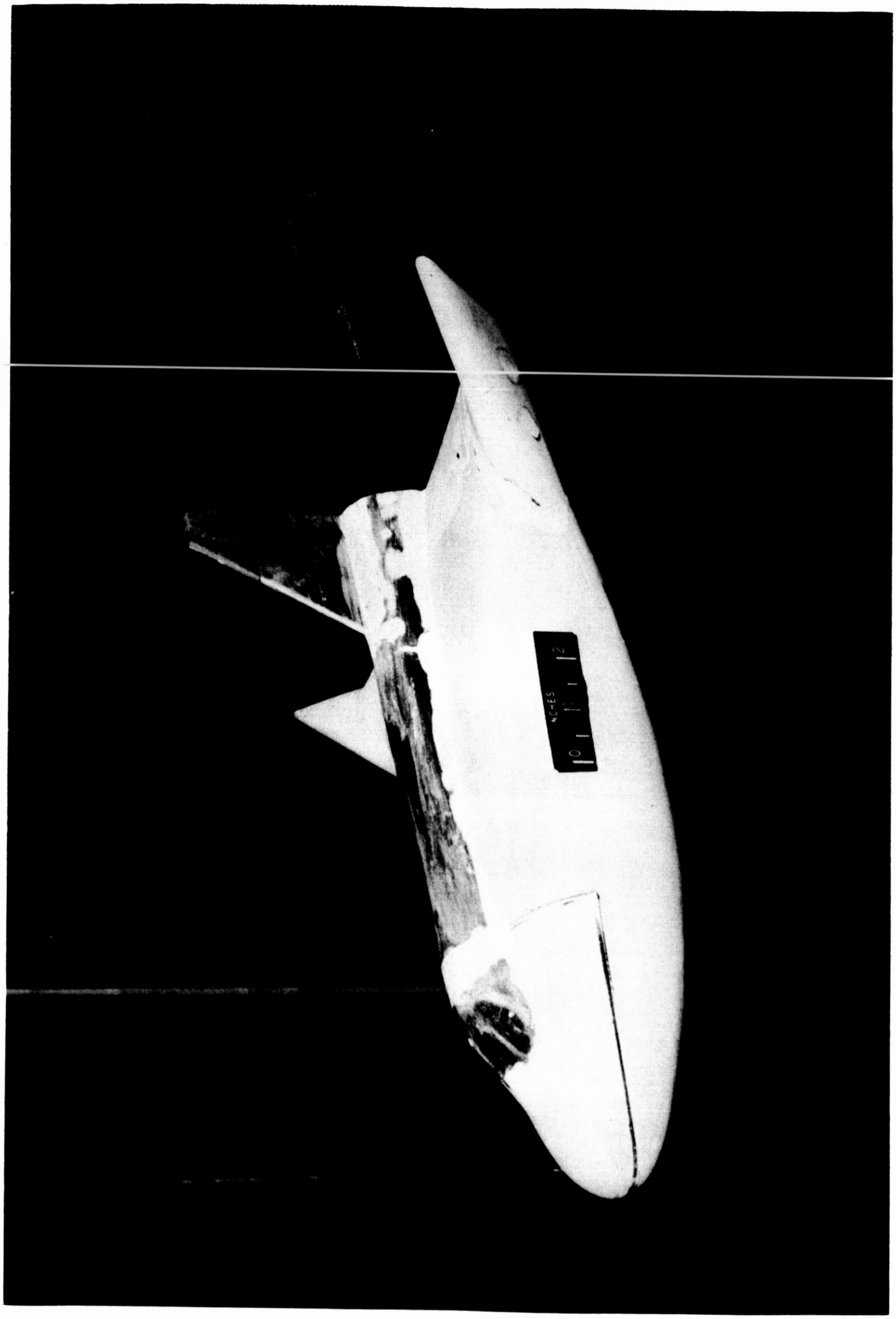


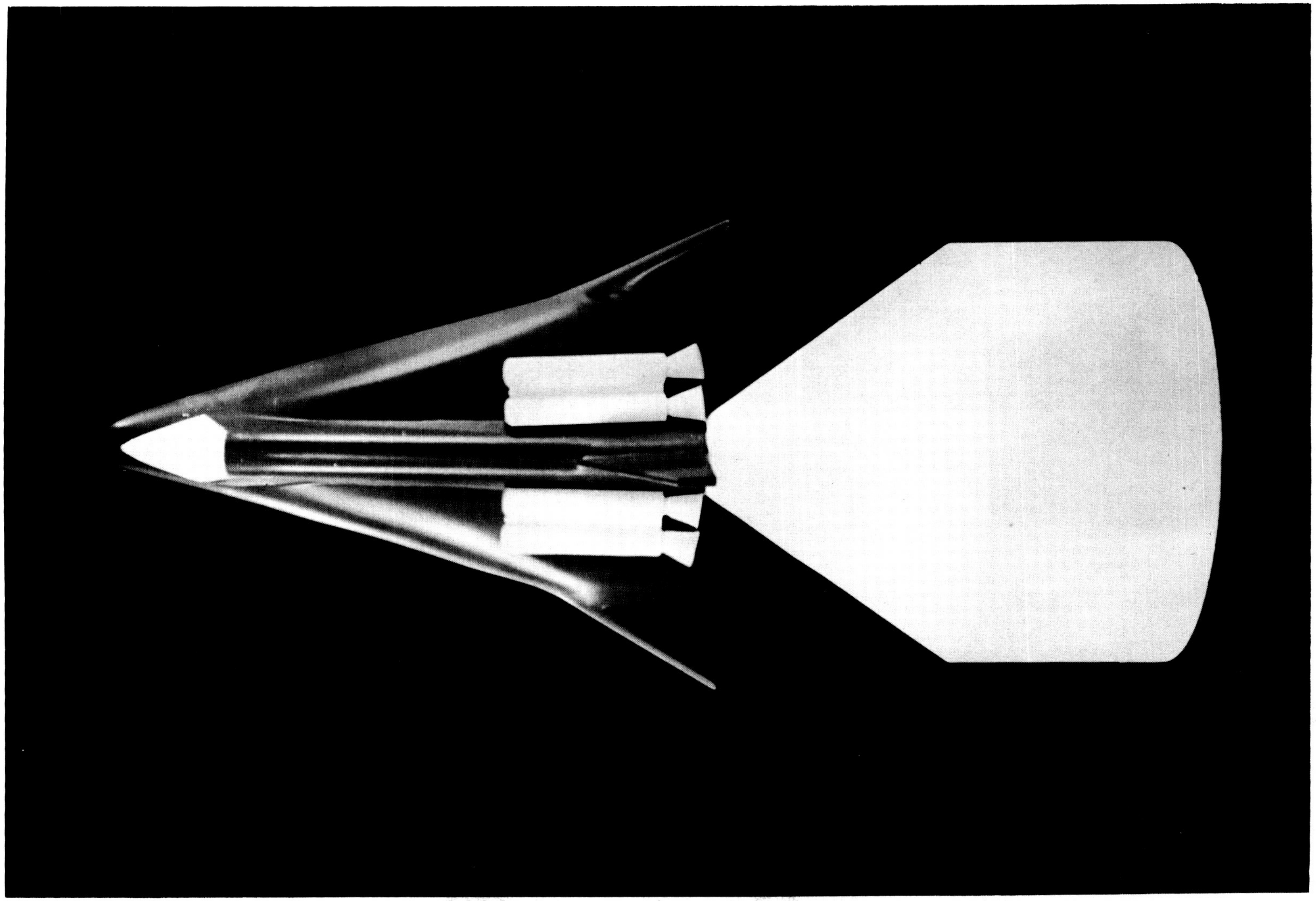
Figure 4.- Model of launch system (Saturn launch vehicle, adapter A, and entry vehicle). (All dimensions in inches unless otherwise noted.)



L-63-9898

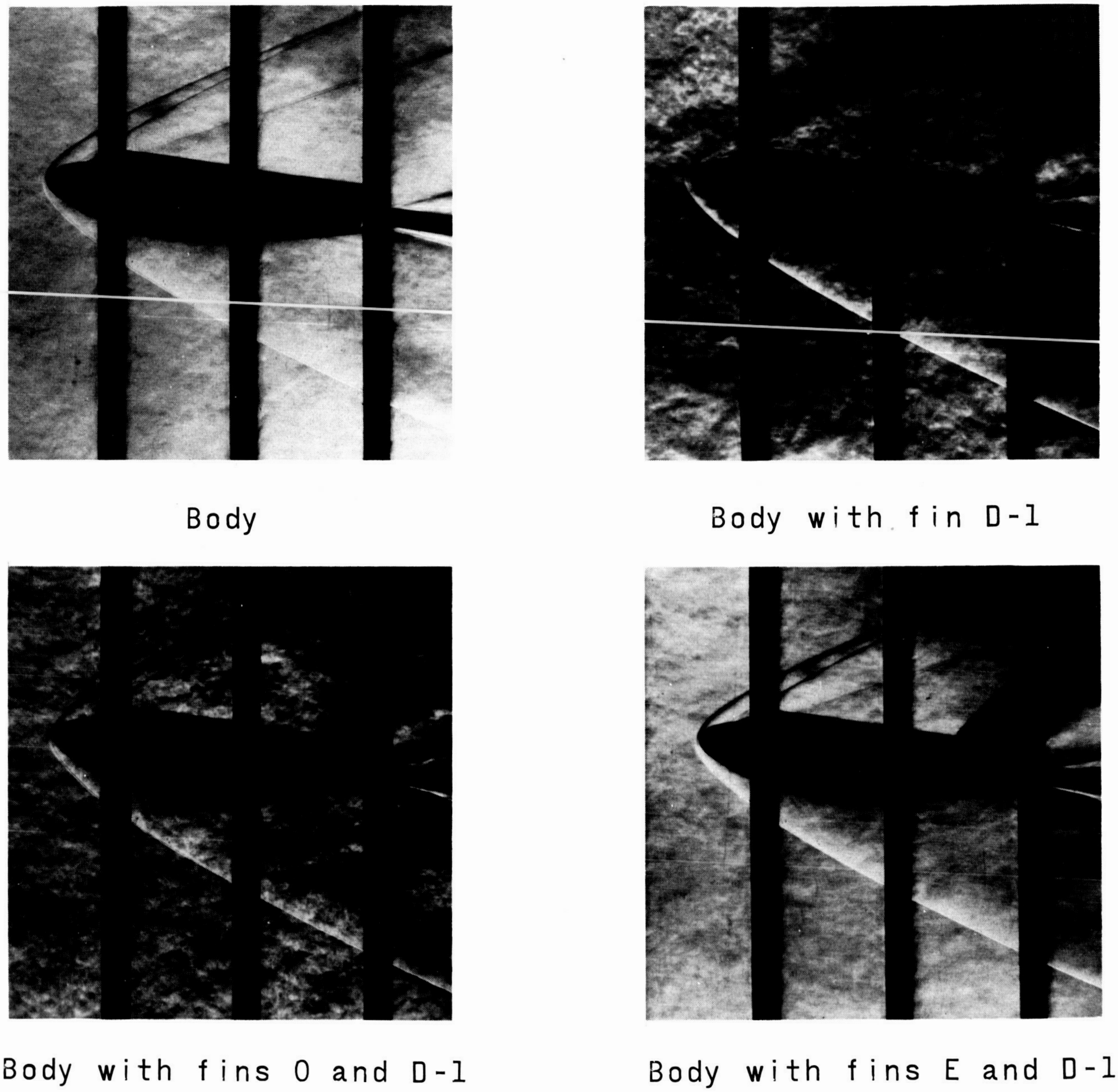
(a) Entry vehicle.

Figure 5.- Model photographs.



(b) Entry vehicle in presence of launch-vehicle adapter section B. L-64-808

Figure 5.- Concluded.

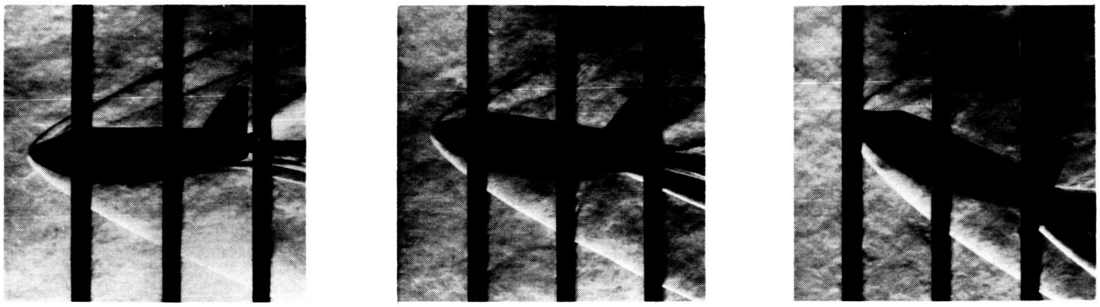


(a) Entry vehicle. $\alpha_{nom} = 8^{o}$; $M = 2.86$. L-65-86

Figure 6.- Typical schlieren photographs of models.

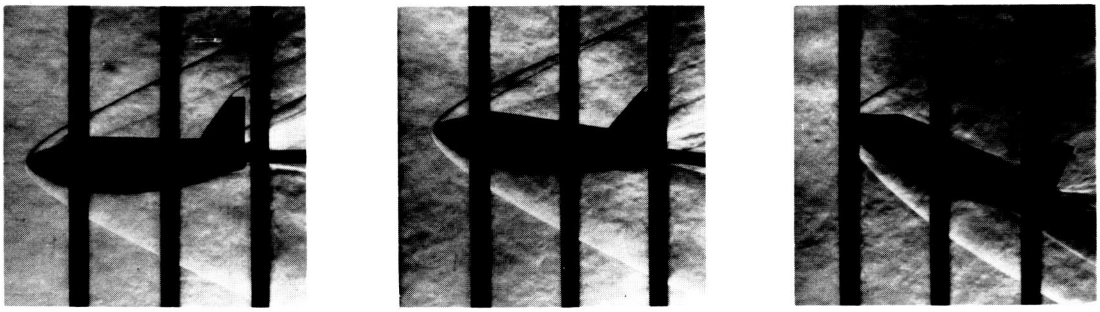
$\alpha_{nom} = 0°$ $\alpha_{nom} = 8°$ $\alpha_{nom} = 24°$

$\delta_e = \delta_a = 0°$



$\alpha_{nom} = 0°$ $\alpha_{nom} = 8°$ $\alpha_{nom} = 24°$

$\delta_e = 30°; \ \delta_a = 0°$

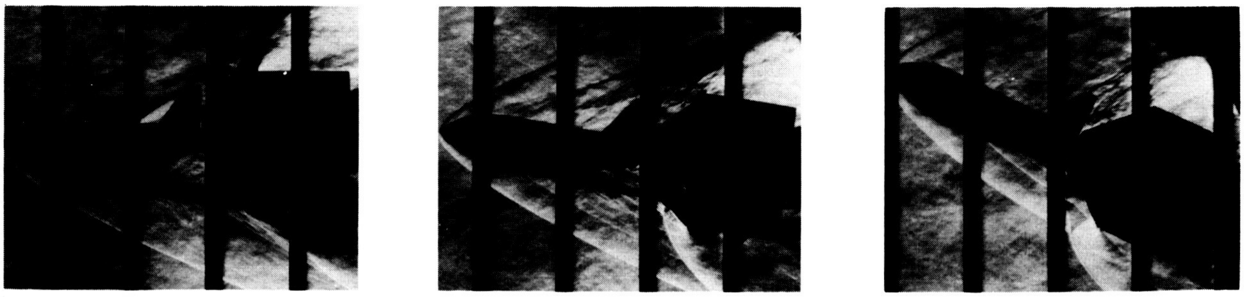


$\alpha_{nom} = 0°$ $\alpha_{nom} = 8°$ $\alpha_{nom} = 24°$

$\delta_e = -30°; \ \delta_a = 0°$

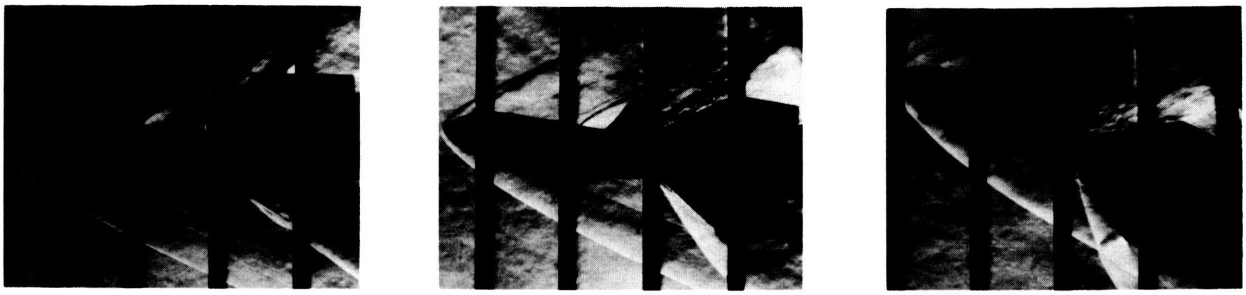
(b) Entry vehicle. Fins E and D-I; M = 2.86. L-65-87

Figure 6.- Continued.



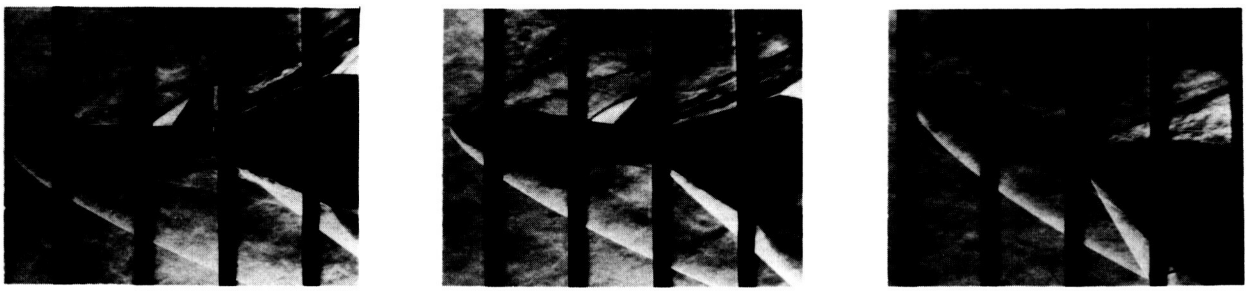
α_{nom} = 0° α_{nom} = 8° α_{nom} = 24°

Launch-vehicle adapter section A



α_{nom} = 0° α_{nom} = 8° α_{nom} = 24°

Launch-vehicle adapter section B

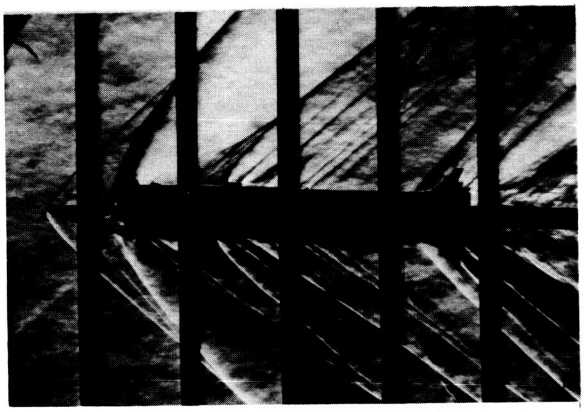


α_{nom} = 0° α_{nom} = 8° α_{nom} = 24°

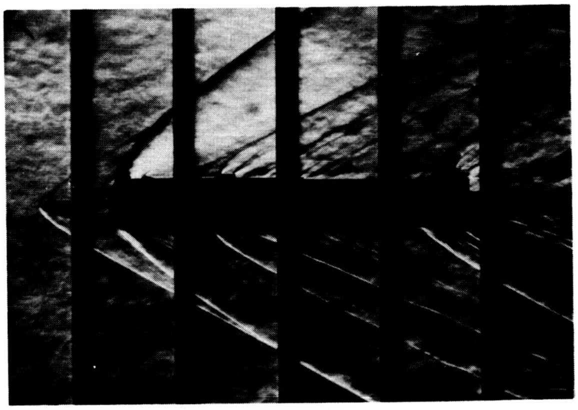
Launch-vehicle adapter section C

(c) Entry vehicle with various adapter sections. M = 2.86. L-65-88

Figure 6.- Continued.



α = 2.5°; M = 1.57

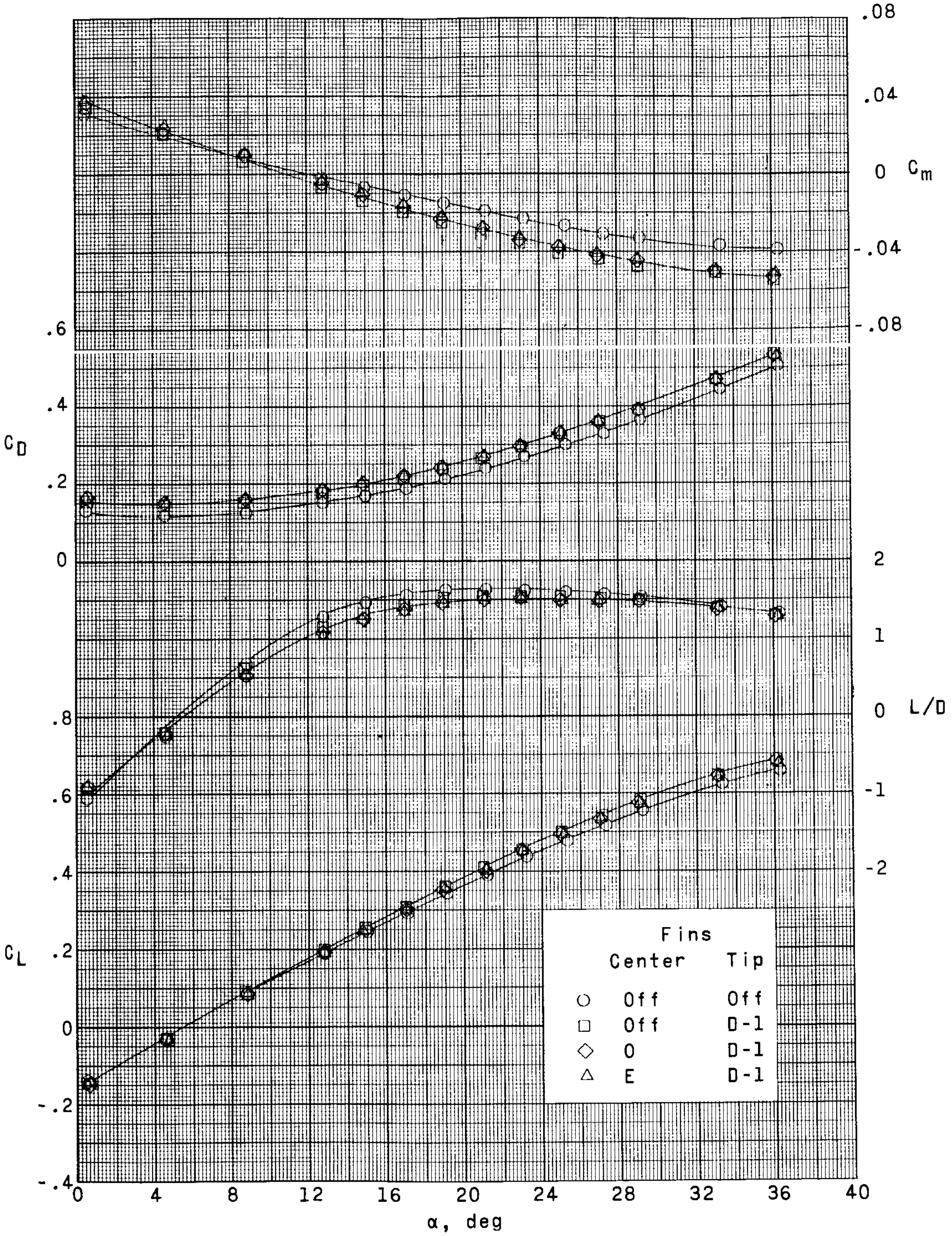


α = 1.5°; M = 2.16

α = 4.0°; M = 2.86

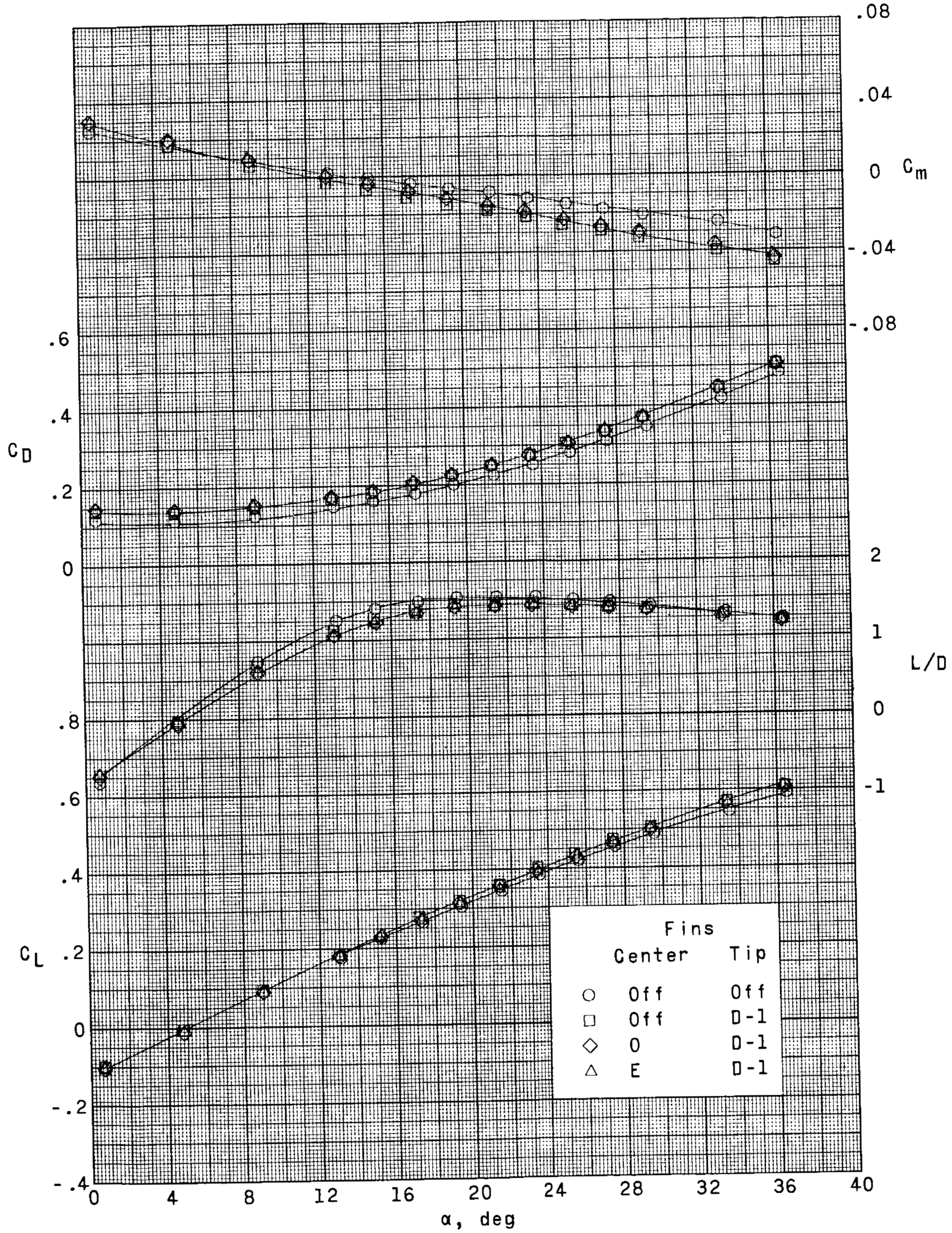
(d) Launch system (Saturn launch vehicle, adapter A, and entry vehicle). Fins E and D-1. L-65-89

Figure 6.- Concluded.



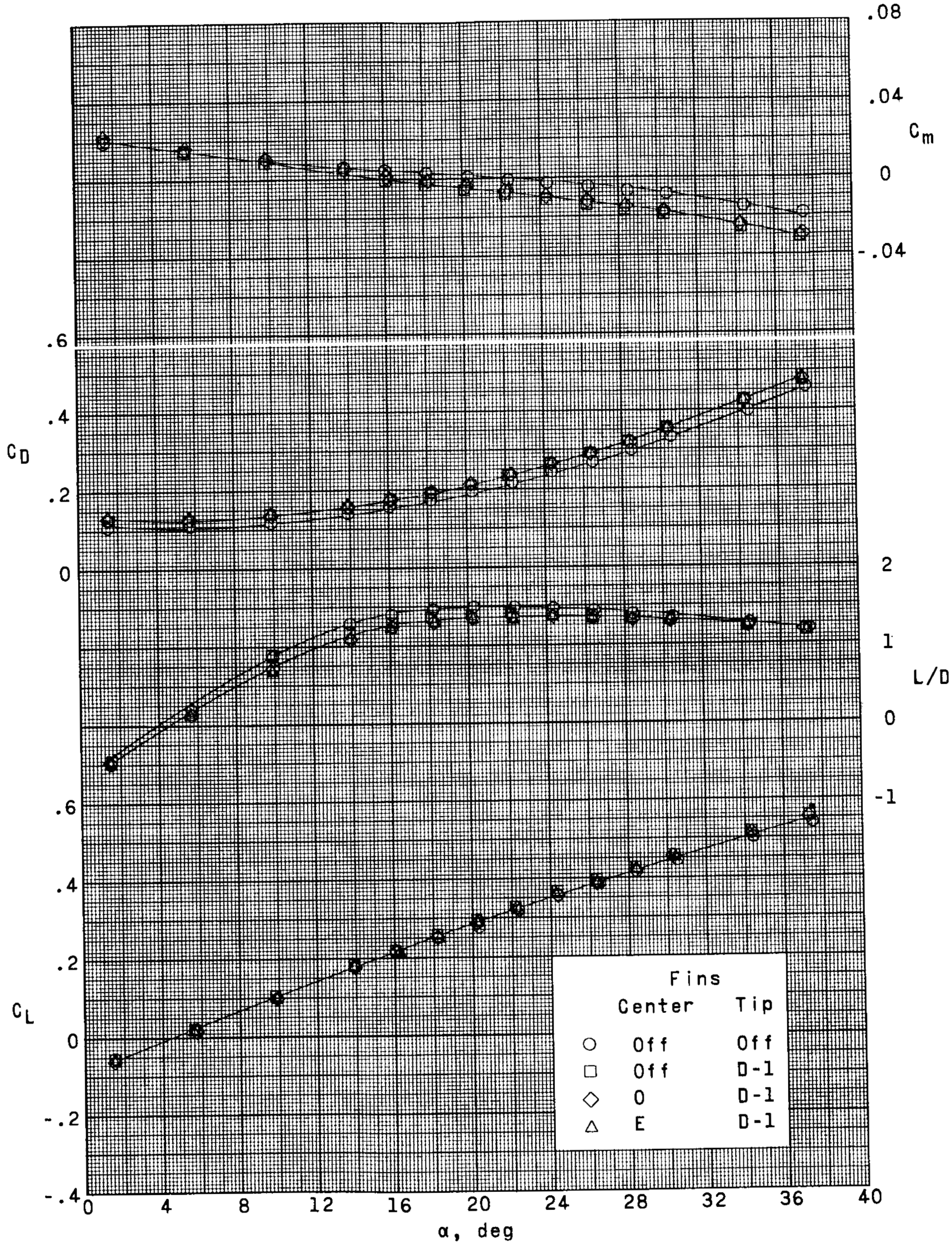
(a) M = 1.50.

Figure 7.- Longitudinal characteristics of entry configuration for various fin arrangements. $\delta_e = \delta_a = 0^{\circ}$.



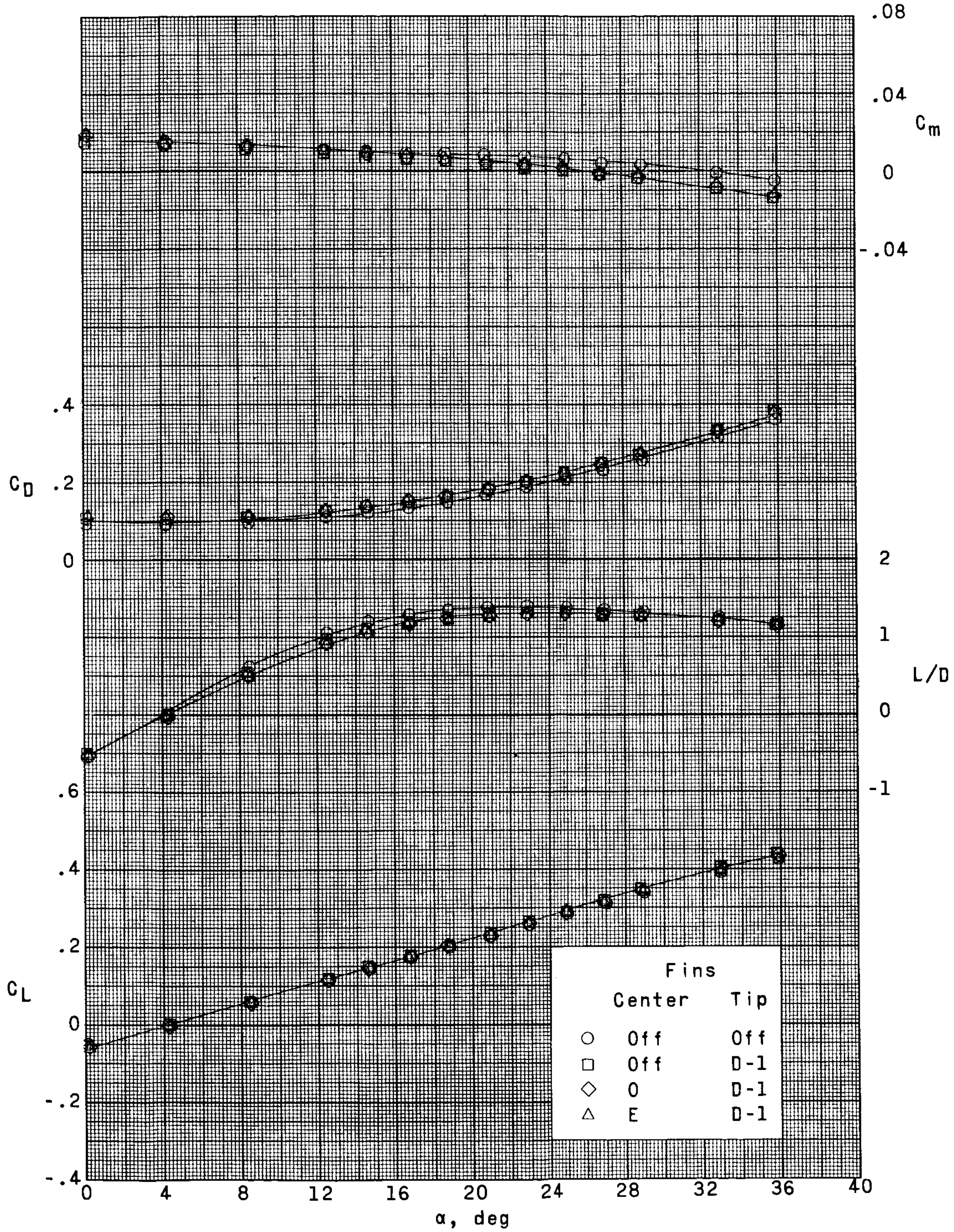
(b) M = 1.80.

Figure 7.- Continued.



(c) M = 2.16.

Figure 7.- Continued.



(d) M = 2.86.

Figure 7.- Concluded.

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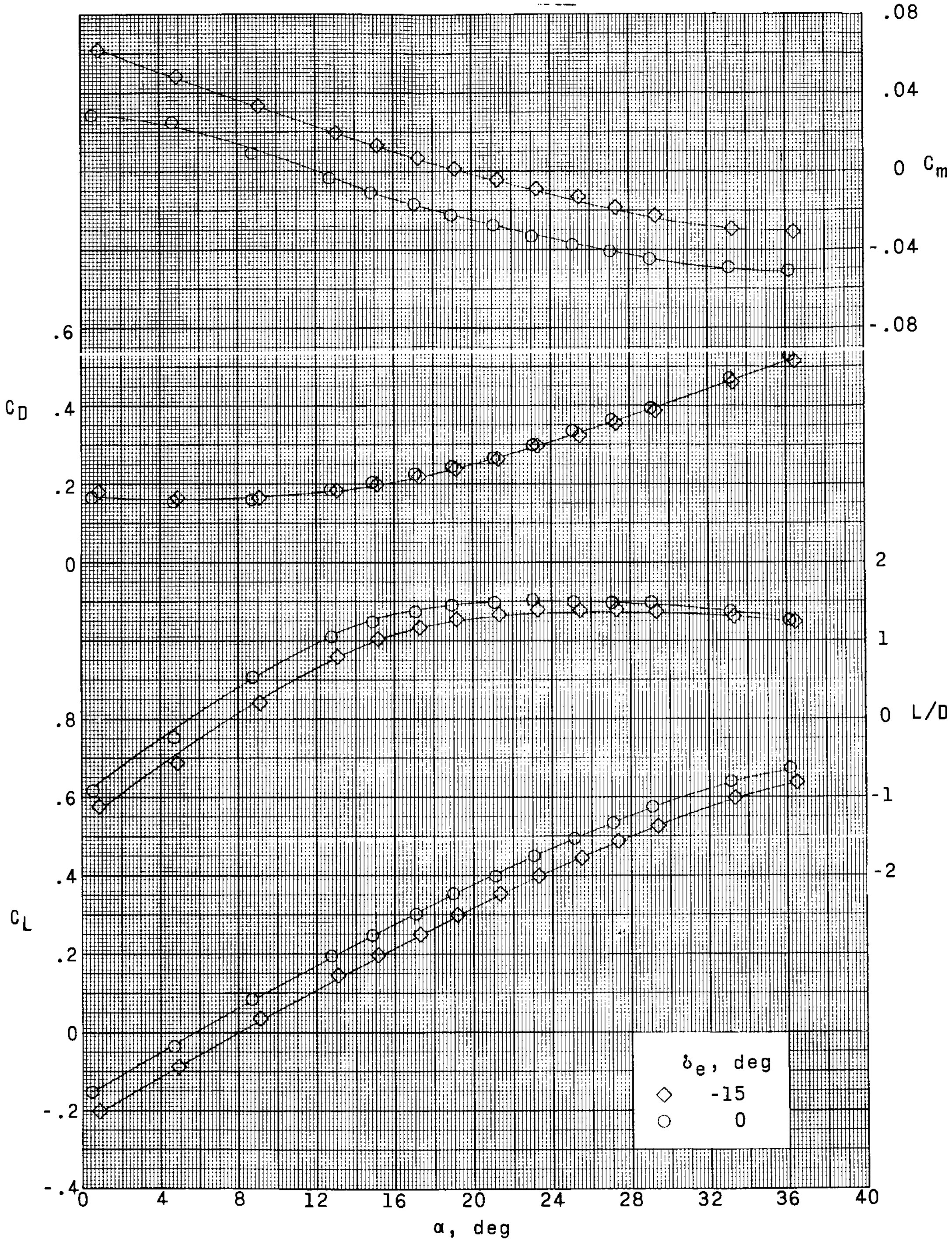
[redacted]



(a) M = 1.50.

Figure 8.- Longitudinal characteristics of entry configuration for various pitch-control deflections. Tip fin D-1; center fin E; $\delta_a = 0^\circ$.

[redacted]

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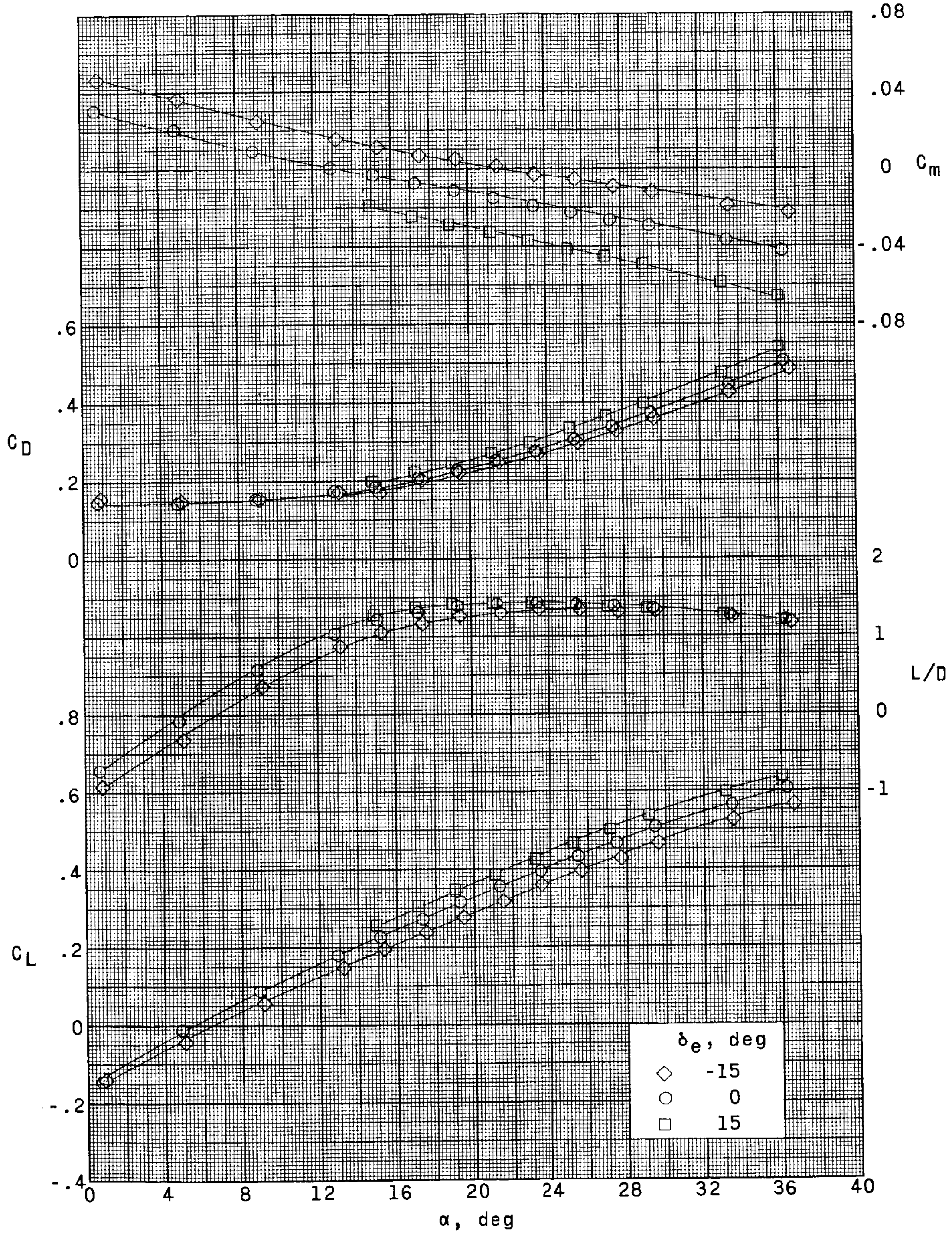
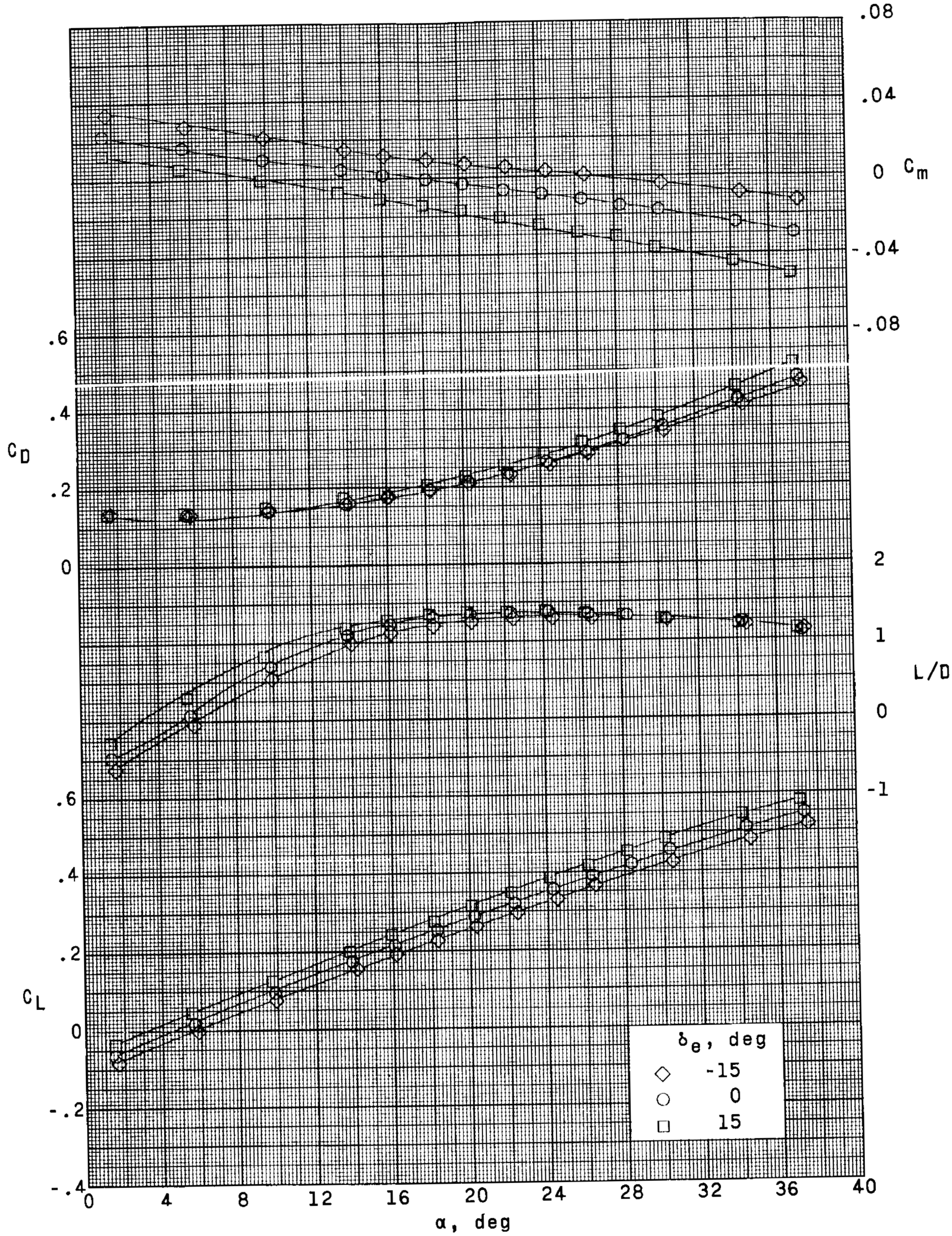


(b) M = 1.80.

Figure 8.- Continued.

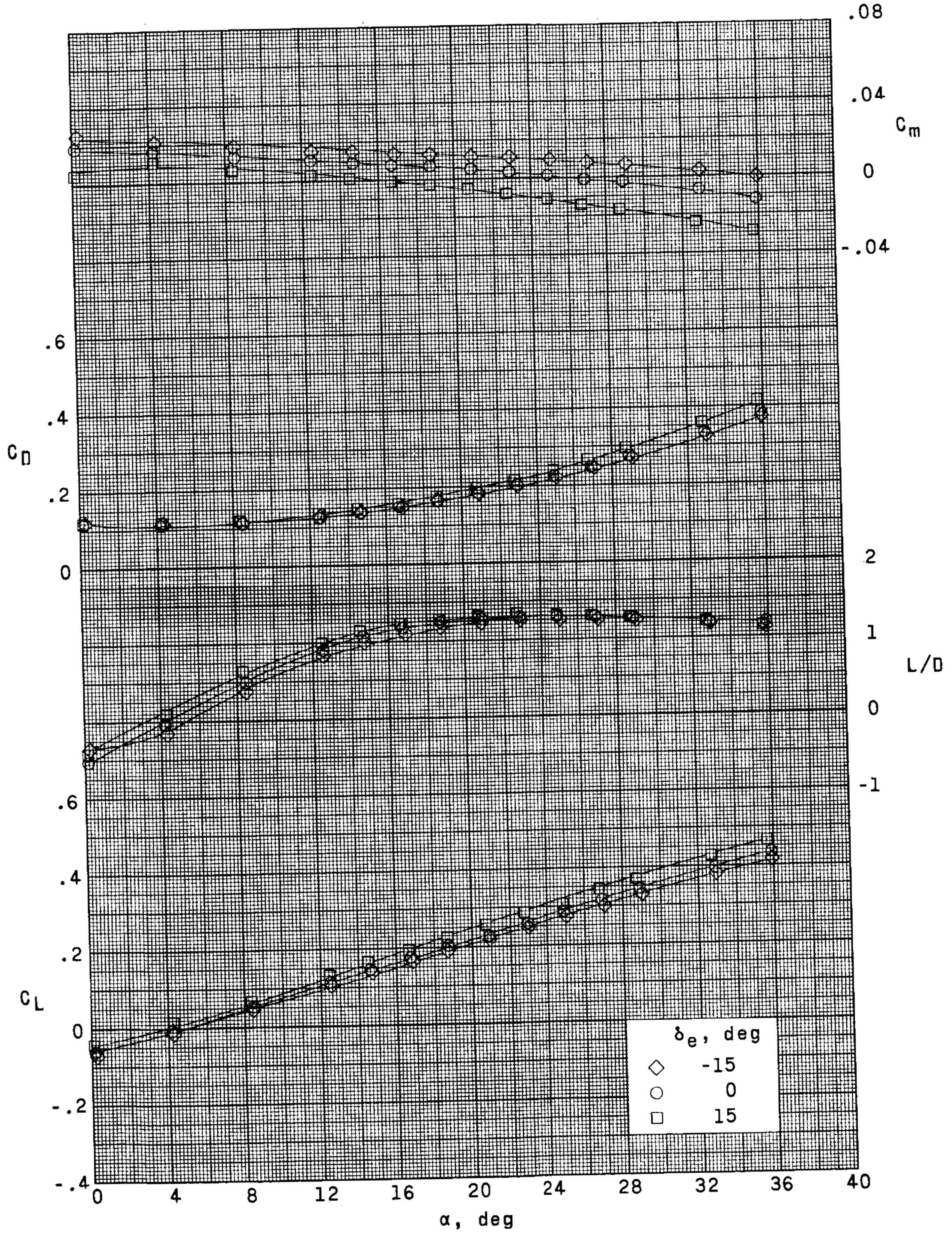
[redacted]



(c) M = 2.16.

Figure 8.- Continued.

[redacted]



(d) M = 2.86.

Figure 8.- Concluded.

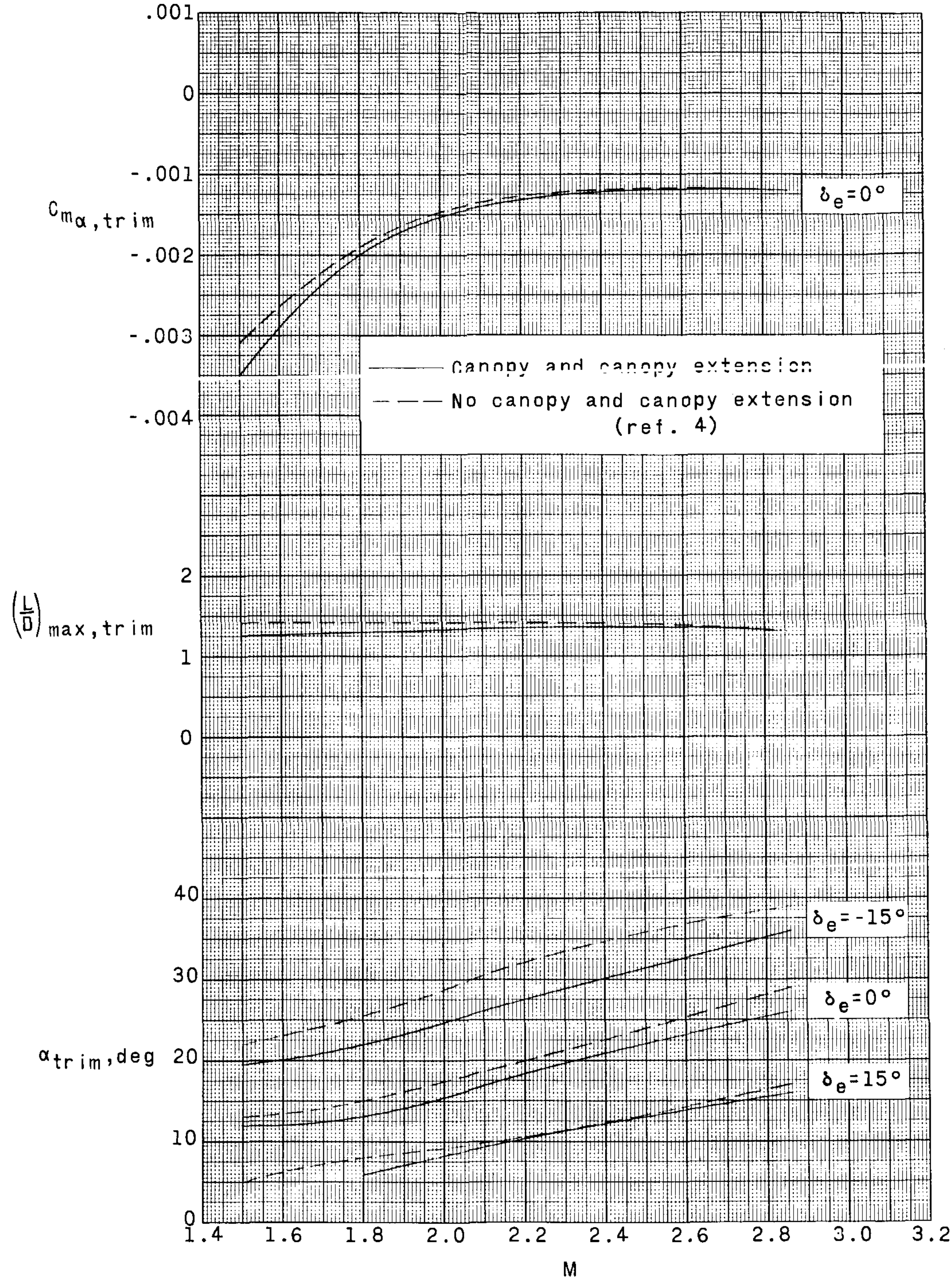
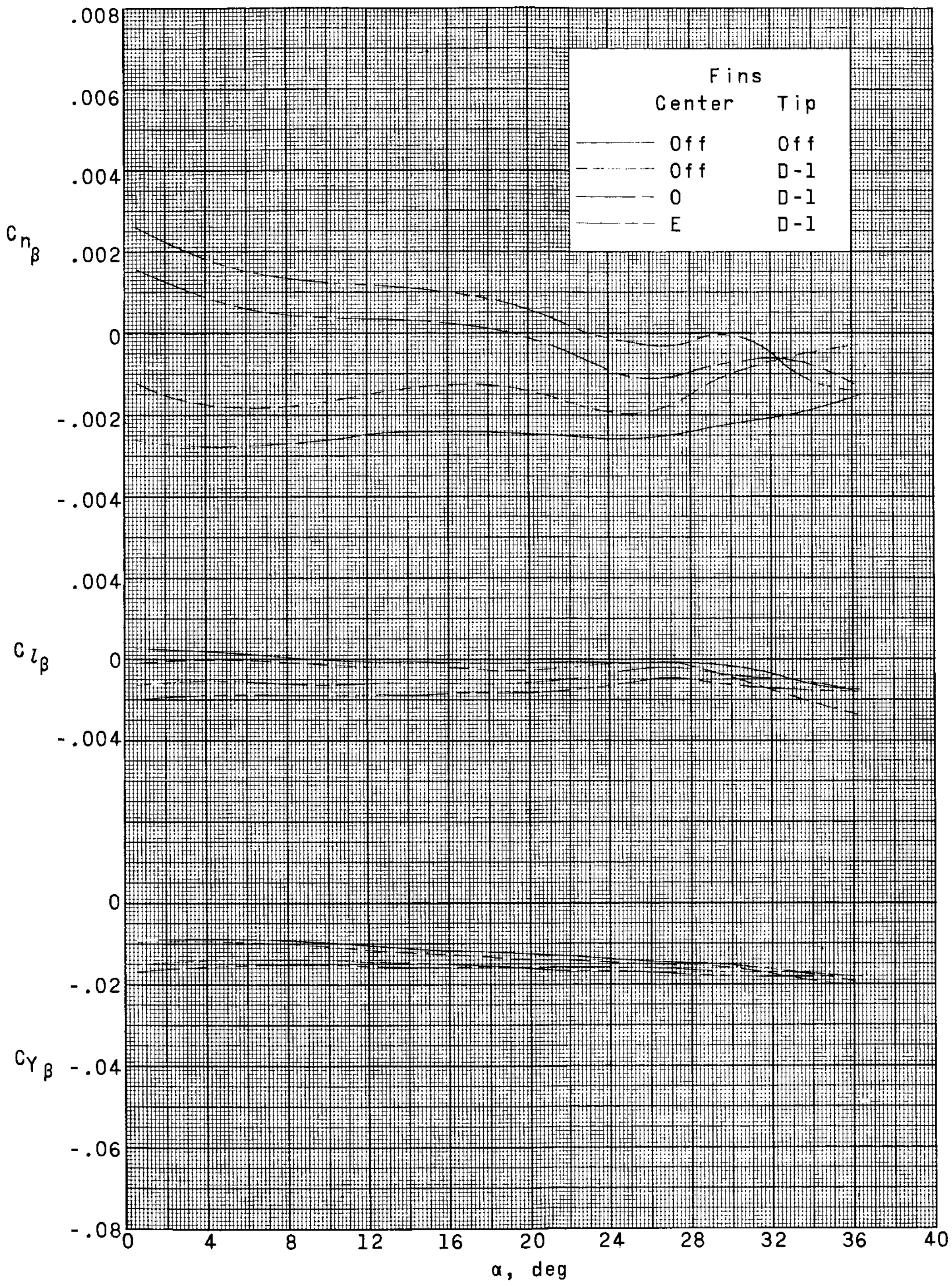
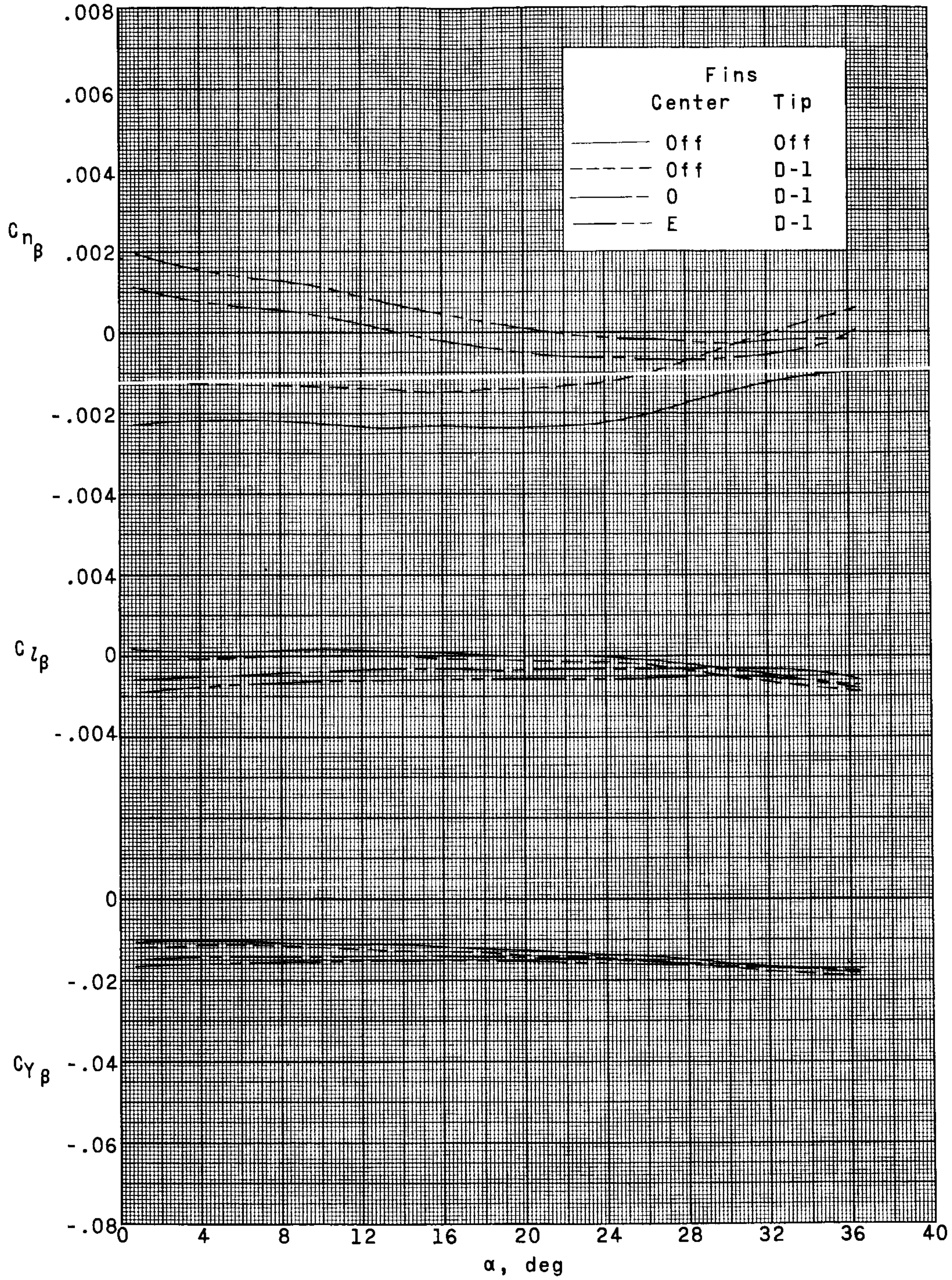


Figure 9.- Effect of canopy and canopy extension on trimmed longitudinal characteristics of entry configuration. Tip fin D-1; center fin E; and $\delta_a = 0°$.



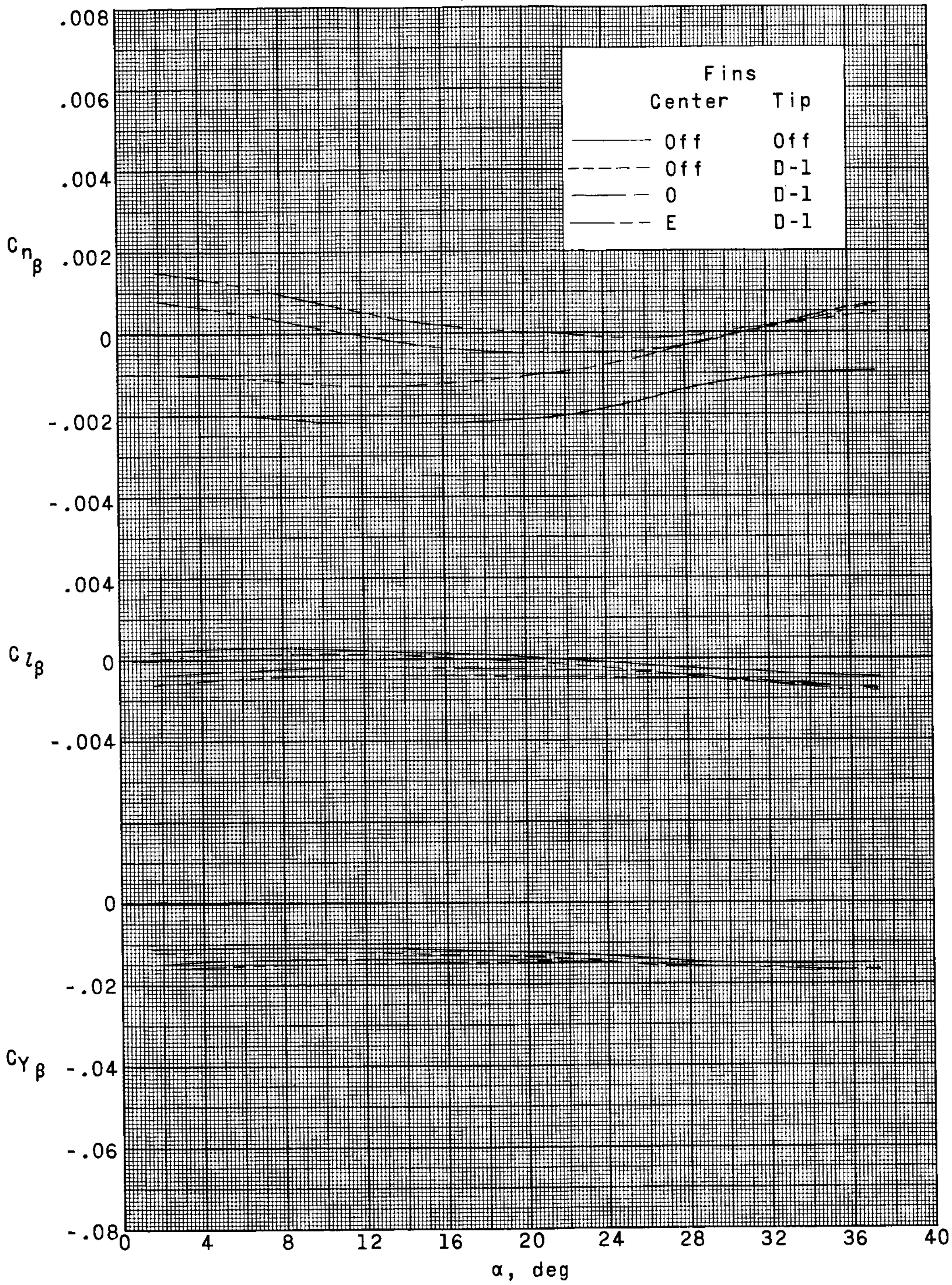
(a) M = 1.50.

Figure 10.- Lateral stability characteristics of entry configuration for various fin arrangements. $\delta_e = \delta_a = 0^\circ$.



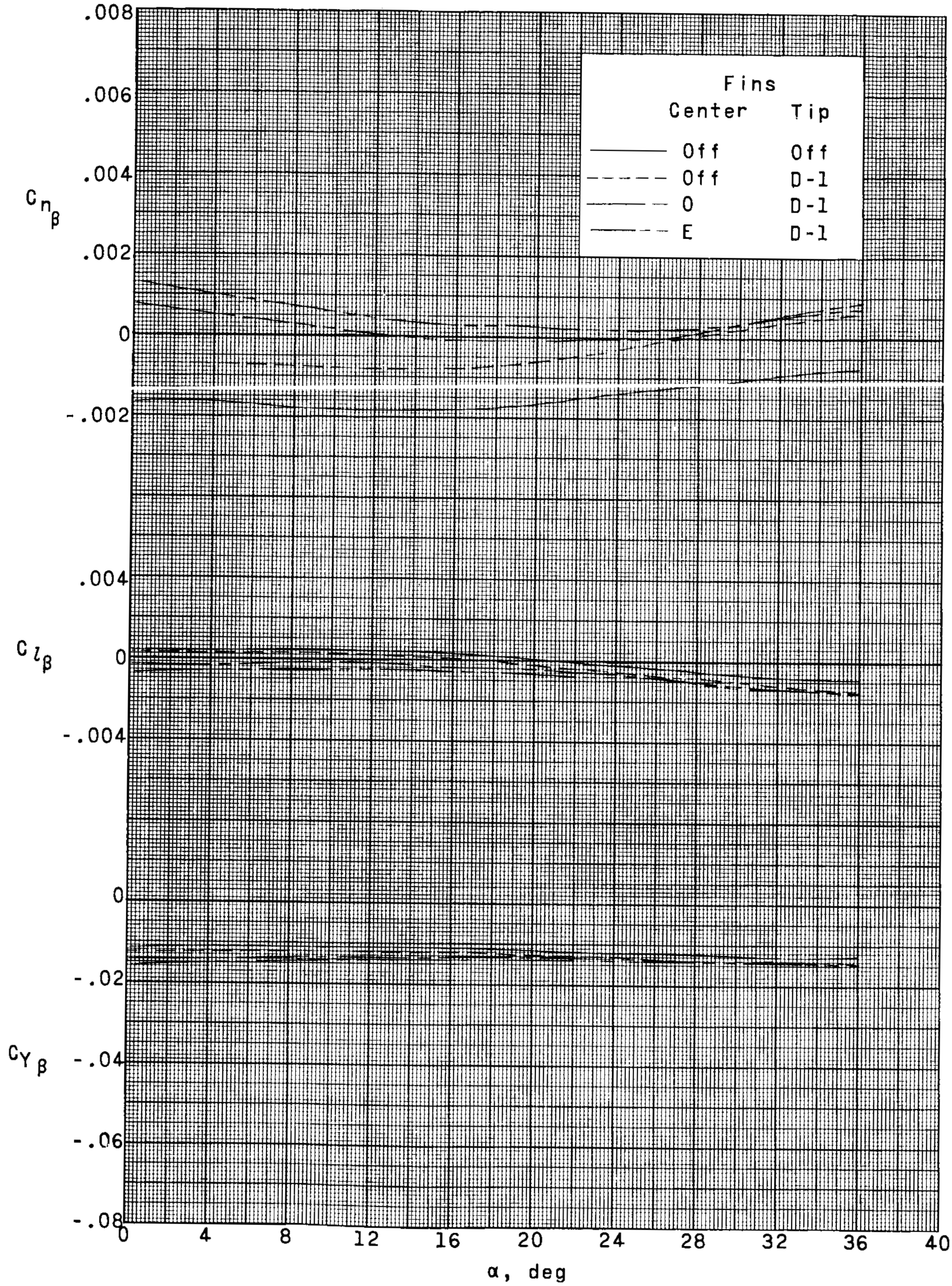
(b) M = 1.80.

Figure 10.- Continued.



(c) M = 2.16.

Figure 10.- Continued.



(d) M = 2.86.

Figure 10.- Concluded.

UNCLASSIFIED

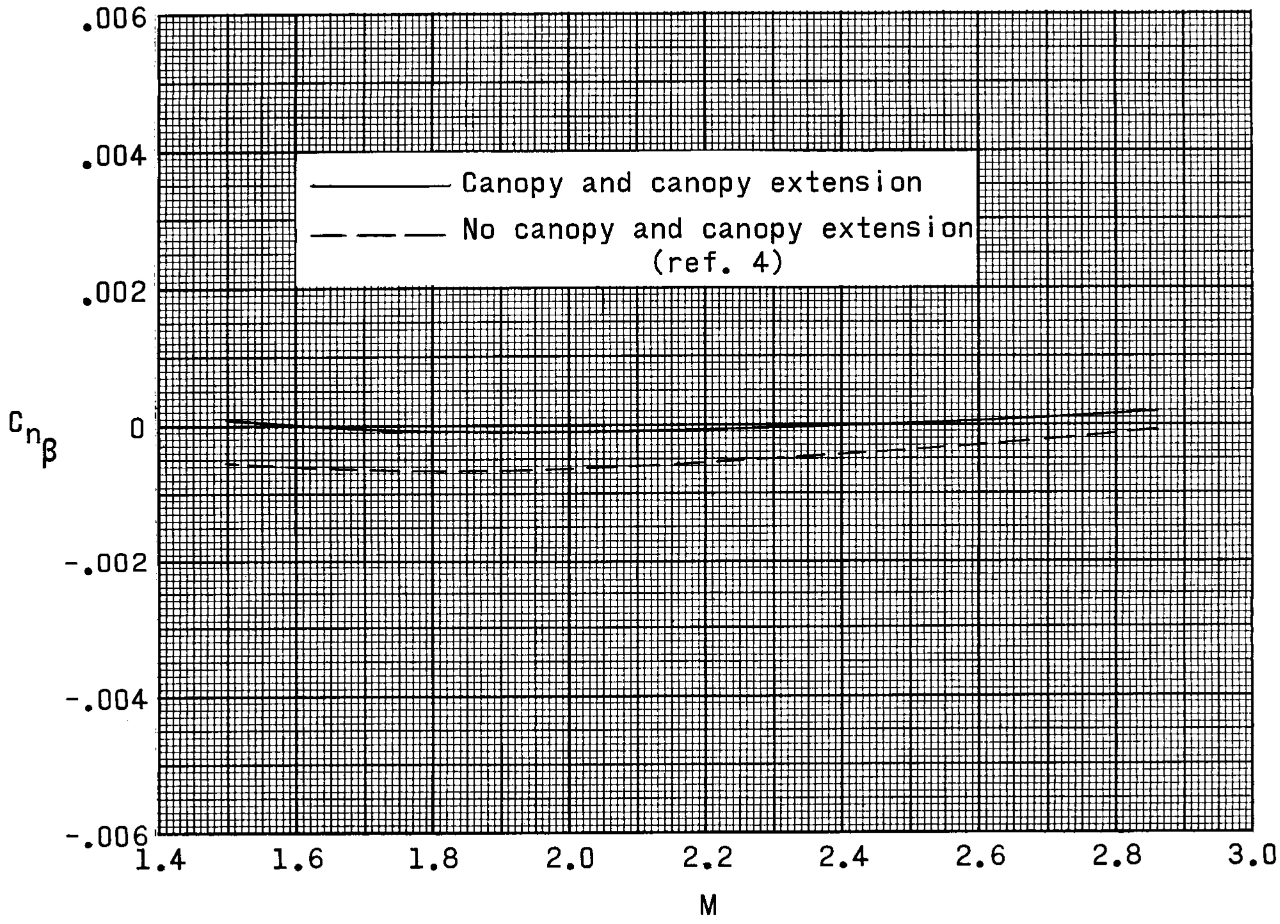


Figure 11.- Effect of canopy and canopy extension on directional-stability parameter of entry configuration. Tip fin D-1; center fin E; $\alpha = 22.5^0$; $\delta_e = \delta_a = 0^0$.

[redacted]

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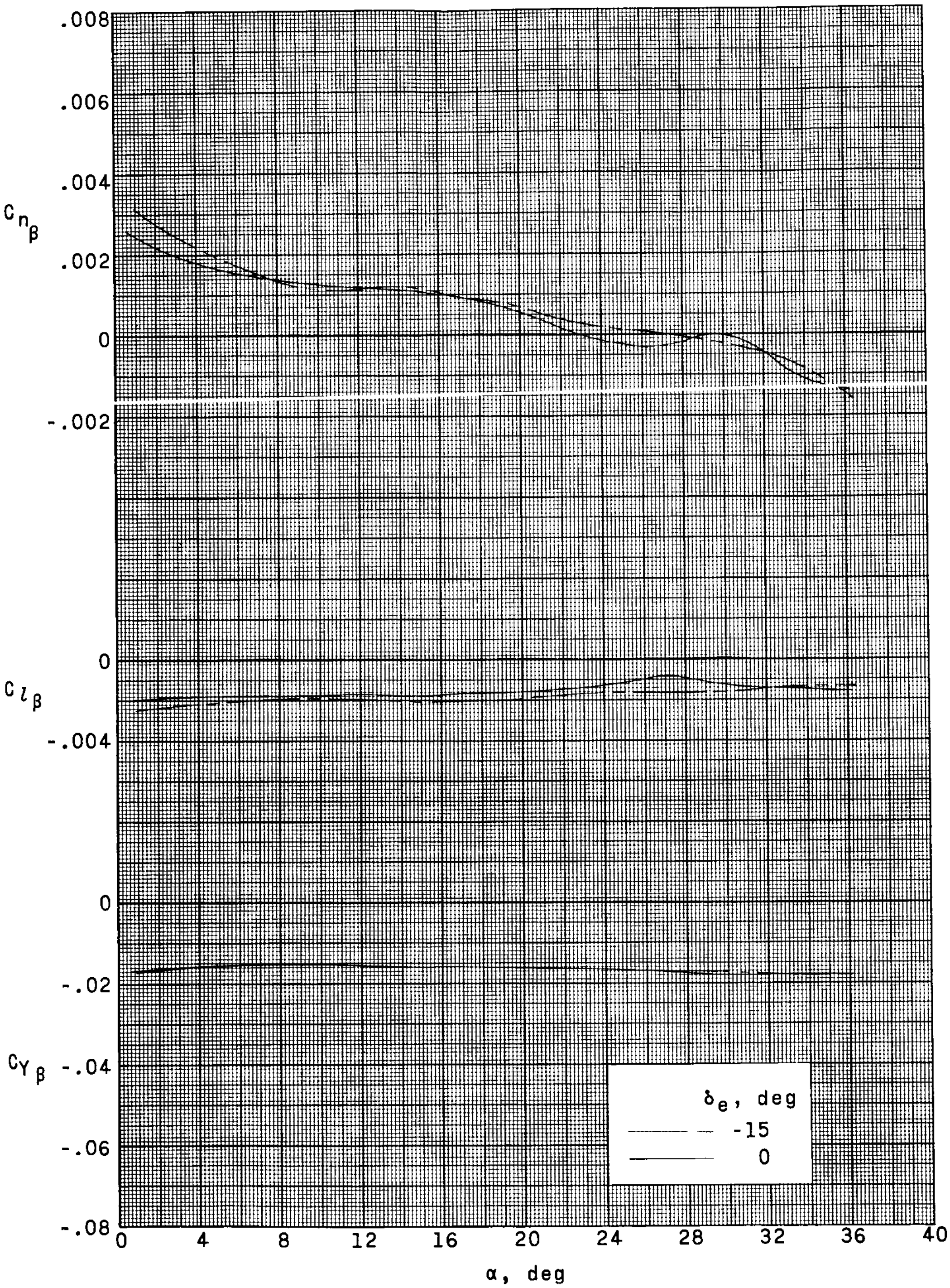
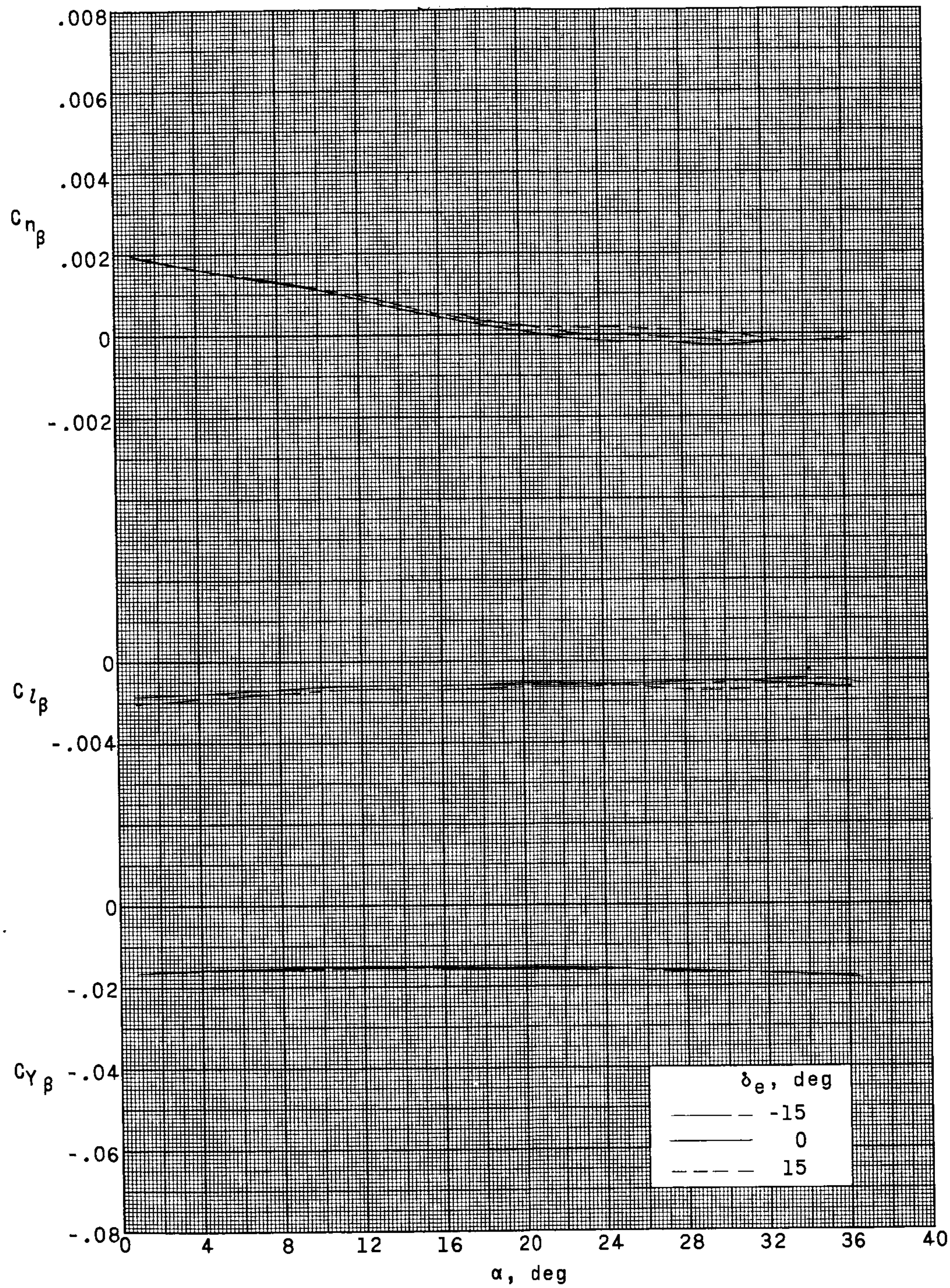


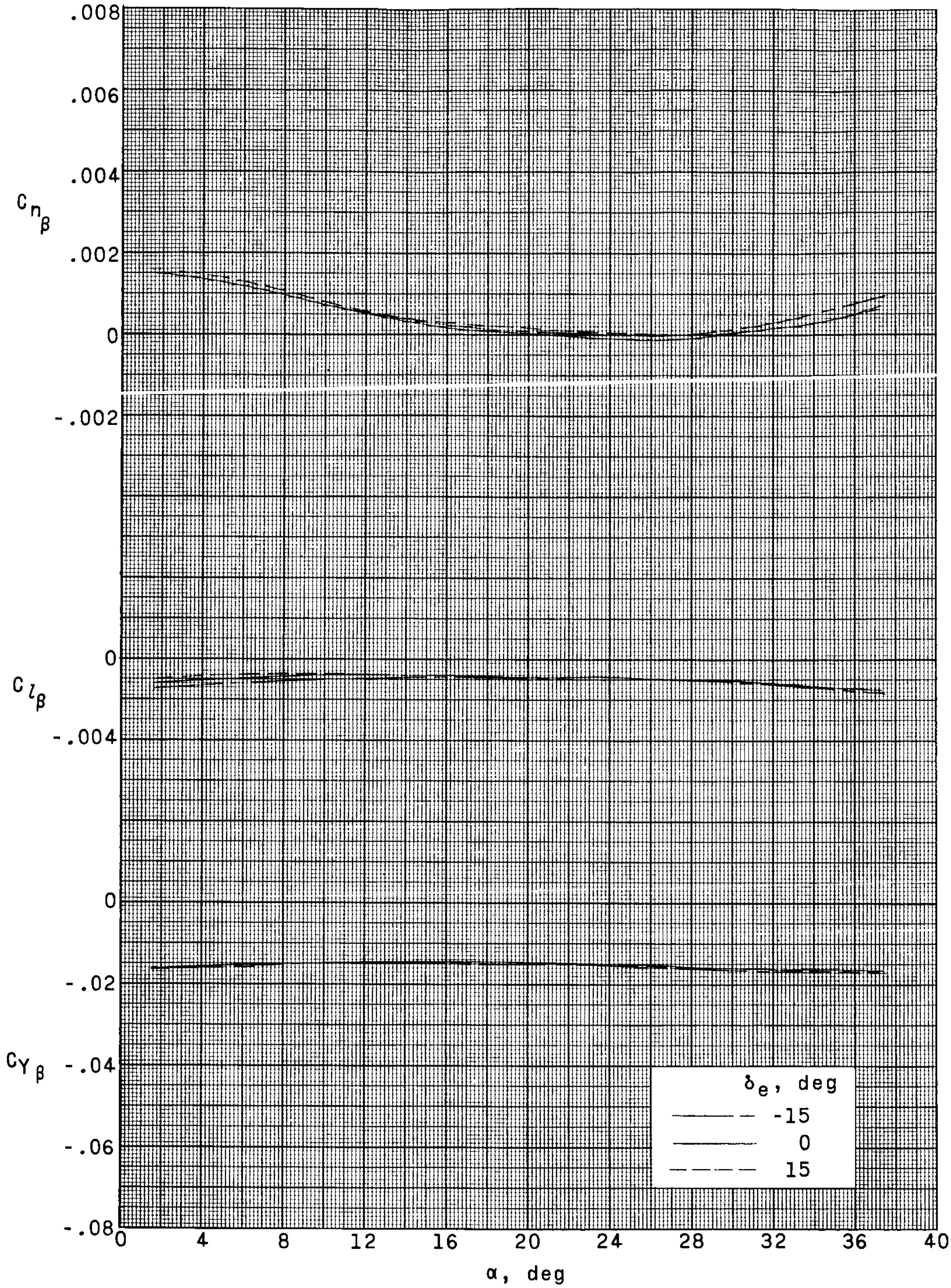
(a) M = 1.50.

Figure 12.- Lateral stability characteristics of entry configuration for various pitch-control deflections. Tip fin D-1; center fin E; $\delta_a = 0^{\circ}$.



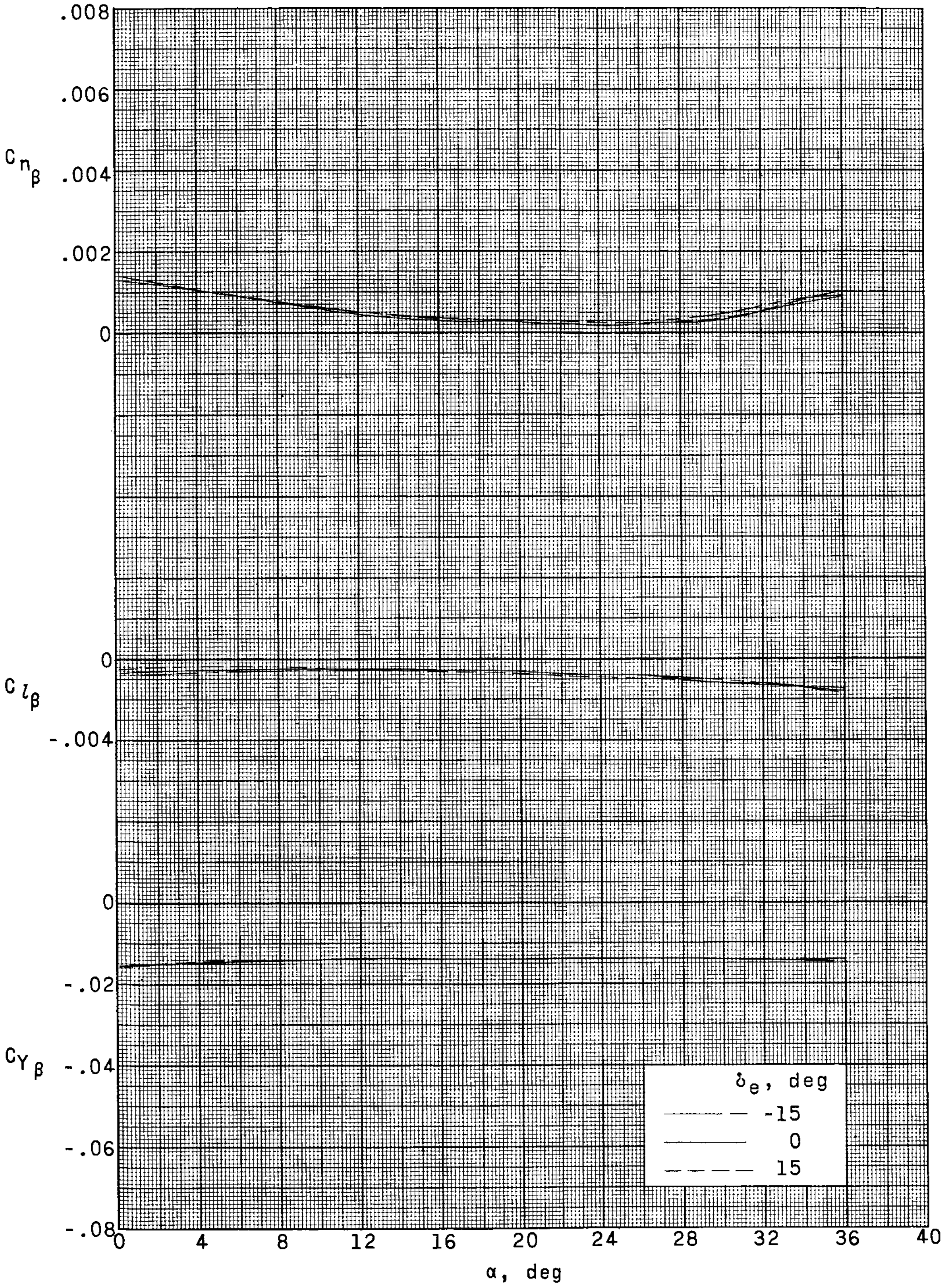
(b) M = 1.80.

Figure 12.- Continued.



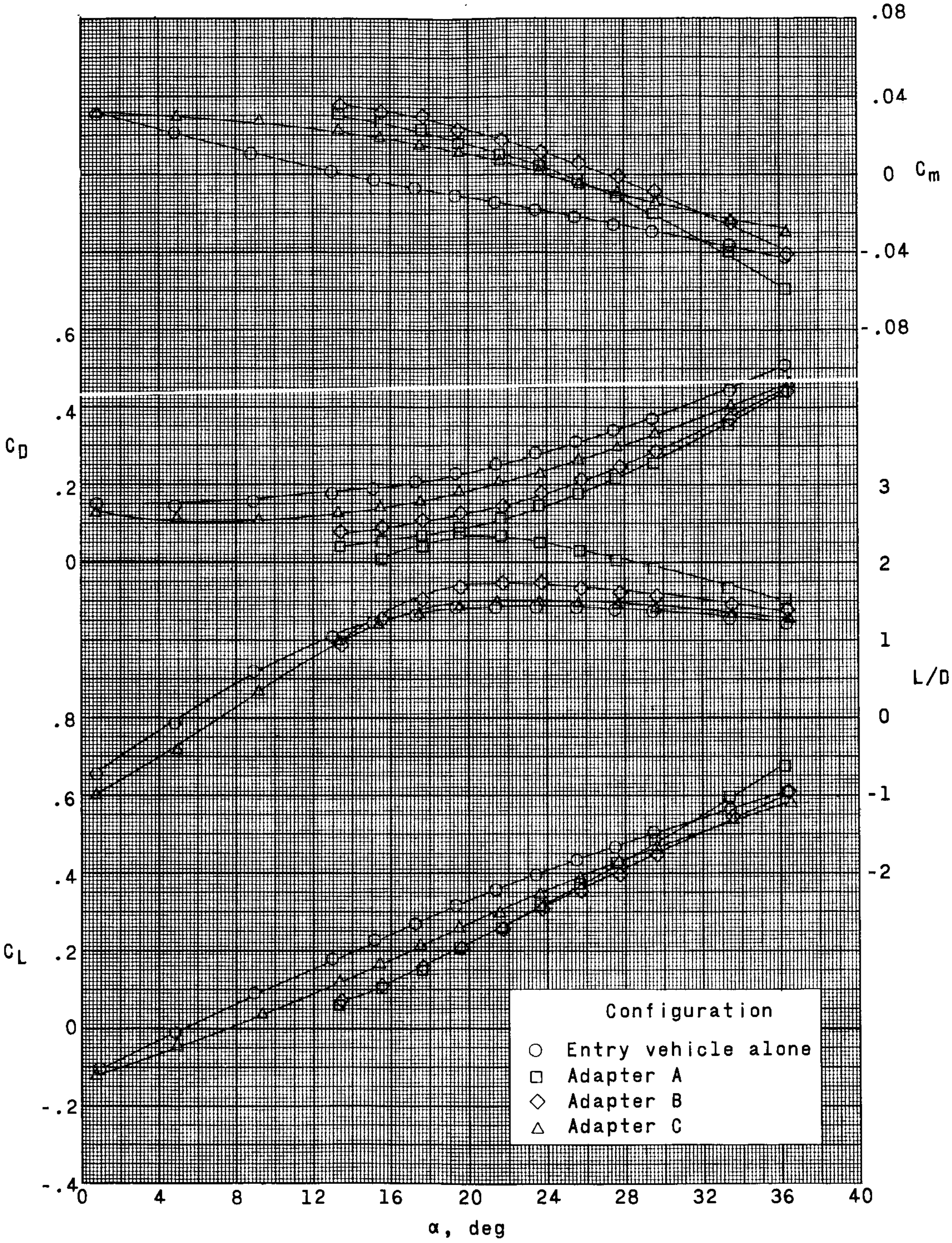
(c) M = 2.16.

Figure 12.- Continued.



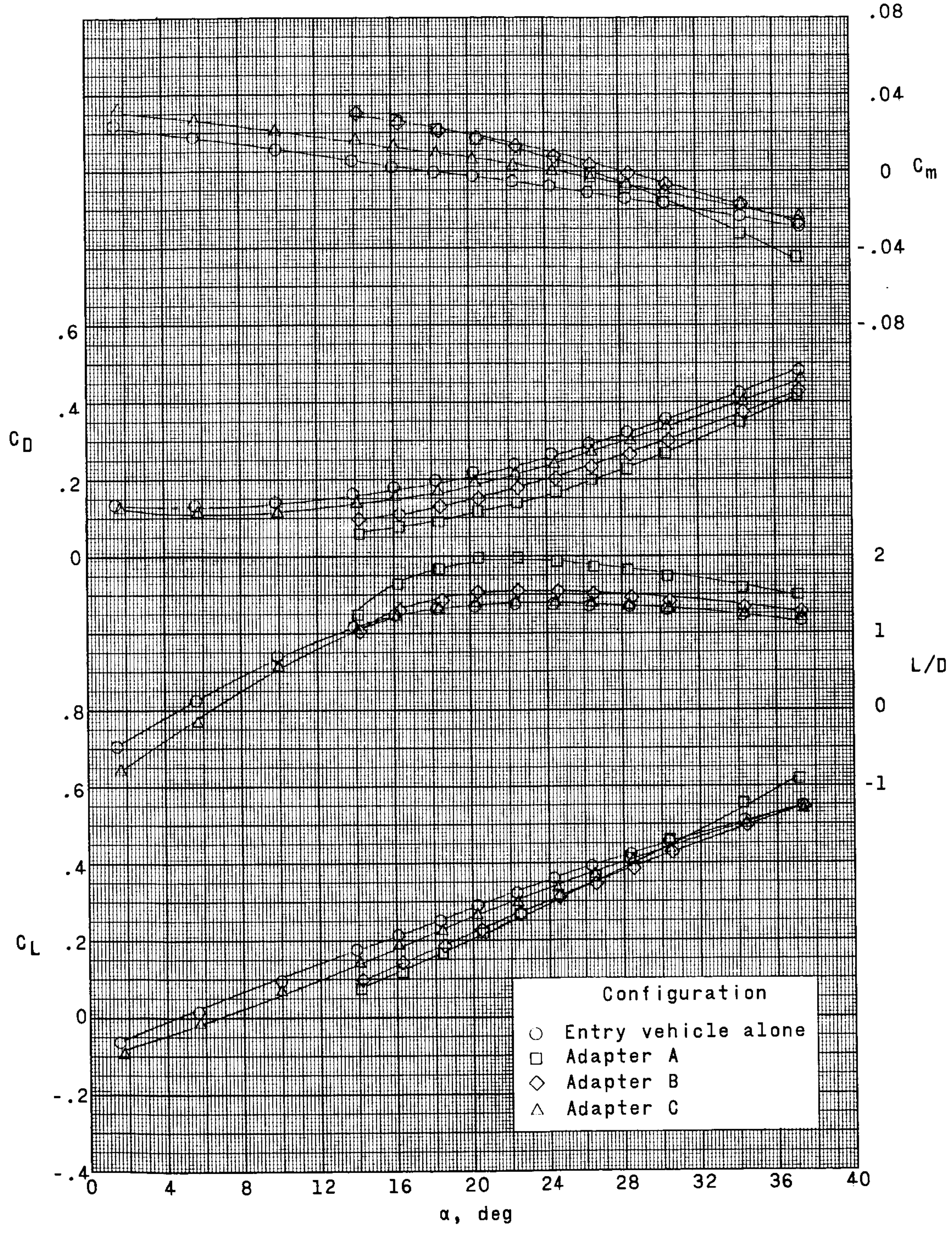
(d) M = 2.86.

Figure 12.- Concluded.



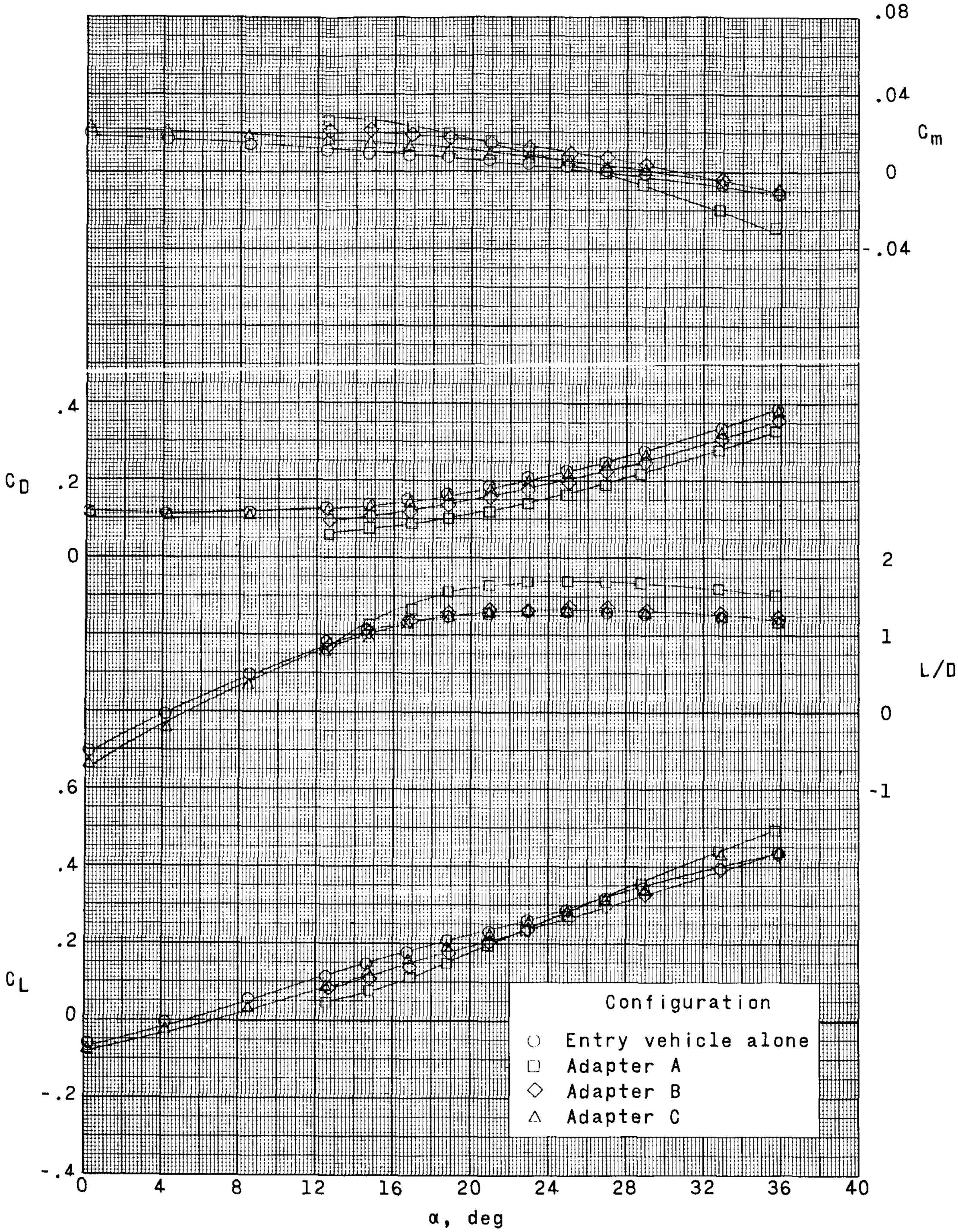
(a) $M = 1.80$.

Figure 13.- Effect of adapter sections on longitudinal characteristics of entry configuration. Tip fin D-1; center fin E; $\delta_e = \delta_a = 0^\circ$.



(b) M = 2.16.

Figure 13.- Continued.



(c) M = 2.86.

Figure 13.- Concluded.

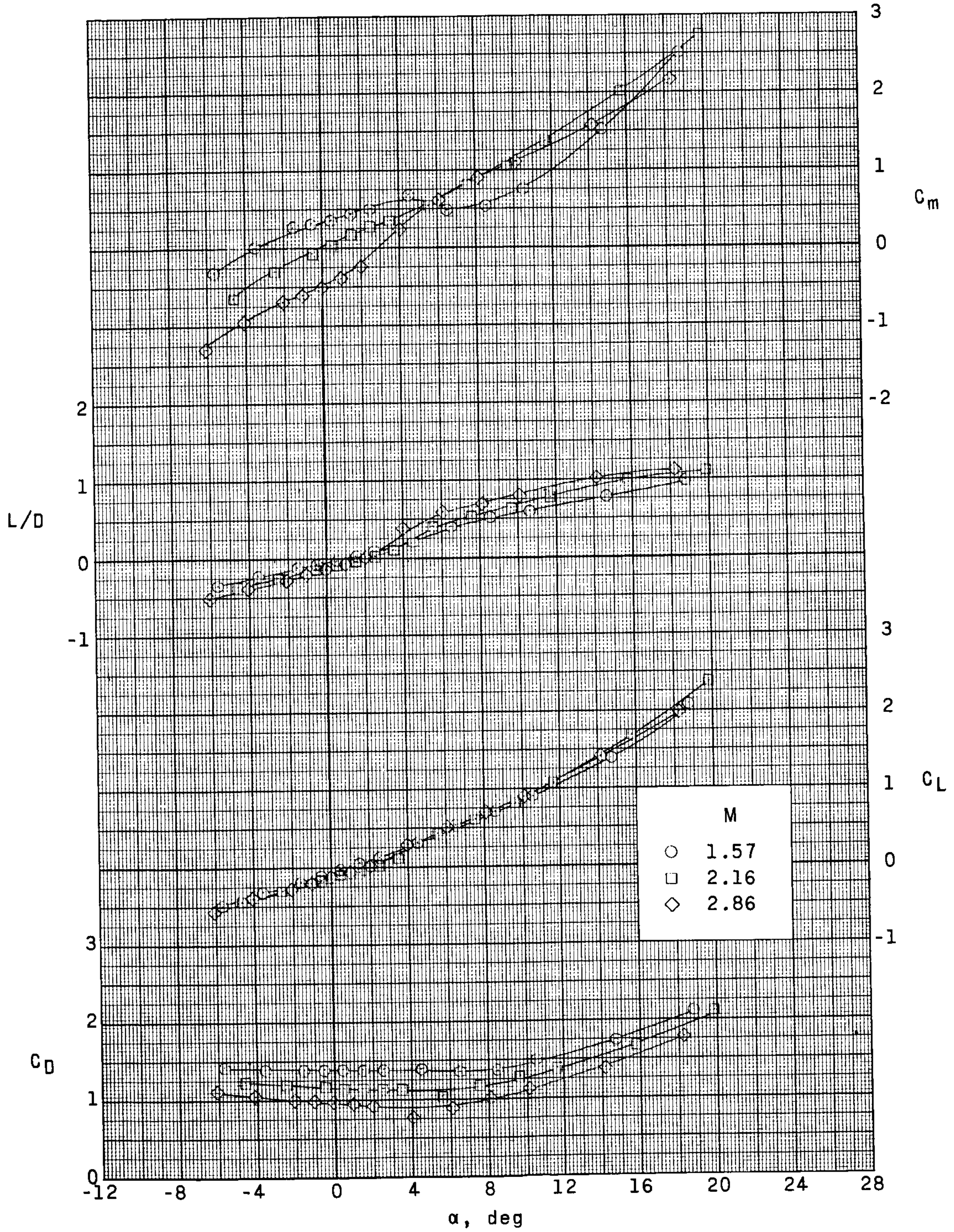


Figure 14.- Longitudinal characteristics of launch system (Saturn launch vehicle; adapter A, and entry vehicle). Tip fin D-1; center fin E; $\delta_e = \delta_a = 0^0$.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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